(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 May 2001 (31.05.2001)

PCT

(10) International Publication Number
WO 01/39413 A2

(51) International Patent Classification[7]: H04J 3/00

(21) International Application Number: PCT/US00/41874

(22) International Filing Date: 2 November 2000 (02.11.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/162,936	2 November 1999 (02.11.1999)	US
60/170,094	10 December 1999 (10.12.1999)	US
60/170,095	10 December 1999 (10.12.1999)	US
60/170,093	10 December 1999 (10.12.1999)	US
60/170,092	10 December 1999 (10.12.1999)	US
60/186,108	1 March 2000 (01.03.2000)	US
60/200,425	28 April 2000 (28.04.2000)	US
09/704,446	1 November 2000 (01.11.2000)	US

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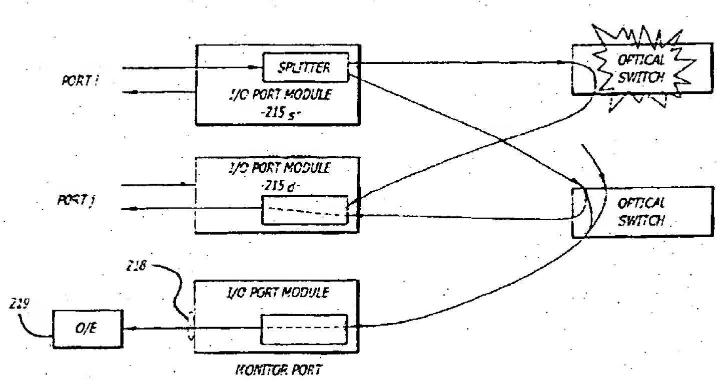
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *Without international search report and to be republished upon receipt of that report.*

[Continued on next page]

(54) Title: 1+1 FAULT PROTECTION IN A NETWORK OF OPTICAL CROSS-CONNECT SWITCHING SYSTEMS



(57) Abstract: The present invention provides methods, systems, and data communication networks for providing fault protection in an optical network. In one embodiment, the present invention includes a source node having an optical cross-connect switching system that has a source port card with a splitter to split an input optical signal into two similar optical signals. The two similar optical signals contain the same information. A source optical switching device switches one of the two similar optical signals to a first destination port card and onto an adjacent node and the other one of the similar optical signals to a second destination port card and onto a different adjacent node, respectively, such that the two similar optical signals are then diversely routed through the optical network. A destination node having an optical cross-connect switching system receives the two similar optical signals via first and second source port cards, respectively. The optical cross-connect switching system of the destination node includes a destination optical switching device to switch each of the two similar optical signals to a destination port card having a selector switch. The selector switch selects one of the available two similar optical signals, such that, if one of the diversely routed similar optical signals fails to reach the destination node, due to a fault in the optical network, the other one of the similar optical signals is still available. Thus, the same information is provided to the destination port card of the destination node and 1+1 optical fault protection is provided for the optical network.

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1+1 FAULT PROTECTION IN A NETWORK OF OPTICAL CROSS-CONNECT SWITCHING SYSTEMS

CROSS REFERENCE TO RELATED APPLICATIONS

This non-provisional U.S. Patent Application claims the benefit of U.S. Provisional Patent Application No. 60/162,936 entitled "OPTICAL CROSSCONNECT WITH OPTICAL TO ELECTRICAL CONVERTERS" filed on November 2, 1999 by inventor Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,094 entitled "OPTICAL CROSSCONNECT WITH BRIDGING, TEST ACCESS AND REDUNDANCY" filed on December 10, 1999 by inventors Rajiv Ramaswami and Robert R. Ward; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,095 entitled "OPTICAL CROSSCONNECT WITH LOW-LOSS BRIDGING, TEST ACCESS, AND REDUNDANCY" filed on December 10, 1999 by inventors Steven Clark and Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,093 entitled "1+1 OPTICAL PROTECTION USING OPTICAL CROSSCONNECT" filed on December 10, 1999 by inventors Rajiv Ramaswami and Robert R. Ward; and also claims the benefit of U.S. Provisional Patent Application No. 60/170,092 entitled "SIGNALING INTERFACE BETWEEN OPTICAL CROSSCONNECT AND ATTACHED EQUIPMENT" filed on December 10, 1999 by inventor Rajiv Ramaswami; and also claims the benefit of U.S. Provisional Patent Application No. 60/186,108 entitled "1:N PROTECTION BETWEEN CLIENTS AND ALL-OPTICAL CROSSCONNECTS" filed on March 1, 2000 by inventors Kent Erickson, Subhashini Kaligotla, and Rajiv Ramaswami which is incorporated herein by reference; and also claims the benefit of U.S. Provisional Patent Application No. 60/200,425 entitled "OPTICAL CROSSCONNECT SYSTEM" filed on April 28, 2000 by inventors Rajiv Ramaswami, Steve Tabaska, and Robert Ward.

BACKGROUND OF THE INVENTION

Over the last few years, the demand for high-speed communication networks has increased dramatically. In many situations, communication networks are implemented with electrical interconnections. That is the interconnections between nodes and networks are made using electronic circuitry such as a transistor switch that blocks or passes electrons. One type of electrical interconnection is an electronic network switch, which is well known. The application of electronic network switches to local area networks (LANs), metropolitan area networks (MANs) and wide area networks (WANs) is also well known. A network switch may stand alone or be used in conjunction with or incorporated into other network equipment at a network node. As desired levels of bandwidth and transmission speed for communication networks increase, it will become more and more difficult for electrical interconnections to satisfy these levels.

One difficulty associated with electrical interconnections is that they are sensitive to external electromagnetic interference. More specifically, electromagnetic fields that reside in the vicinity of the interconnection lines induce additional currents, which may cause erroneous signaling. This requires proper shielding, which hampered general heat removal.

Another difficulty is that electrical interconnections are subject to excessive inductive coupling, which is referred to as "crosstalk". To alleviate crosstalk, the electrical interconnections must abide by fundamental rules of circuit routing so that they are set at a distance large enough to prevent neighboring signals from having any adverse effect on each other, which would reduce network performance.

In lieu of electrical interconnections switching electrons or a voltage and current, optical interconnections offer a solution to the difficulties affecting conventional electrical interconnections. Optical interconnections switch photons or light ON and OFF at one or more wavelengths to provide signaling. An advantage of

optical interconnections is that they are not as susceptible to inductive or even capacitive coupling effects as electrical interconnections. In addition, optical interconnections offer increased bandwidth and substantial avoidance of electromagnetic interference. This advantage of optics becomes more important as the transmission rates increase and as the strength of mutual coupling associated with electrical interconnections is proportional to the frequency of the signals propagating over these interconnections.

Albeit local or global in nature, many communications network features electronic switching devices to arbitrate the flow of information over the optical interconnections (e.g. fiber optic cables such as in a Synchronous Optical Network (SONET)). Conventional electronic switching devices for optical signals are designed to include a hybrid optical-electrical semiconductor circuit employing photodetectors, electrical switches, optical modulator or lasers. The incoming optical signals are converted to electrical signals by photodetectors. The electrical signals are amplified and switched by electronic switches to the appropriate output and then converted into optical signals by lasers. One disadvantage associated with a conventional electronic switching device is that it provides less than optimal effectiveness in supporting high data transmission rates and bandwidth.

For example, a Synchronous Optical Network (SONET) is both a standard and a set of specifications for building high speed, digital communications networks that run over fiber-optic cables while interfacing with existing electrical protocols and asynchronous transmission equipment. A SONET network often is a self-healing network. This refers to a network that automatically restores connections among nodes in the event of a link or node failure in a path from a source node to a destination node. There is a growing trend and reliance on such networks owing to increasing reliance on and use of high-speed communication networks and the requirement that these communication networks be robust in the case of certain failures. Self-healing networks typically detect and report a failure, establish and connect a restoration path

and then return the network to normal communications. Such self-healing characteristics are incorporated, for example, in the Synchronous Optical Network (SONET) protocols.

Often SONET utilizes what is termed 1+1 fault protection. In 1+1 protection, traffic is transmitted simultaneously on two separate fibers (usually over disjoint routes) from a source node to a destination node. Generally, one fiber is termed the working fiber and the other fiber is termed the protection fiber. The destination node typically selects one of the two fibers for reception. If that fiber is cut, the destination node simply switches over to the other fiber (e.g. the protected fiber) and continues to receive data. This form a protection is very fast and requires no signaling protocol between the two ends.

A disadvantage associated with SONET based networks is that it provides less than optimal effectiveness in supporting high data transmission rates and bandwidth versus what would be possible with an all optical network. Further, the restoration time of a SONET based network is rather limited as opposed to the restoration time that would be possible with an all optical network.

SUMMARY OF THE INVENTION

The present invention provides methods, systems, and data communication networks for providing fault protection in an optical network. In one embodiment, the present invention includes a source node having an optical cross-connect switching system that has a source port card with a splitter to split an input optical signal into two similar optical signals. The two similar optical signals contain the same information. A source optical switching device switches one of the two similar optical signals to a first destination port card and onto an adjacent node and the other one of the similar optical signals to a second destination port card and onto a different adjacent node, respectively, such that the two similar optical signals are then diversely routed through the optical network. A destination node having an optical cross-connect switching

system receives the two similar optical signals via first and second source port cards, respectively. The optical cross-connect switching system of the destination node includes a destination optical switching device to switch each of the two similar optical signals to a destination port card having a selector switch. The selector switch selects one of the available two similar optical signals, such that, if one of the diversely routed similar optical signals fails to reach the destination node, due to a fault in the optical network, the other one of the similar optical signals is still available. Thus, the same information is provided to the destination port card of the destination node and 1+1 fault optical protection is provided for the optical network.

Accordingly, the present invention provides an optical, scalable cross-connect system with a variety features such as redundancy for fault protection and rapid restoration that can be used to implement 1+1 fault protection. Furthermore, the present invention provides an all optical, scalable cross-connect system which performs switching operations of light signals without converting and reconverting signals between the optical domain to the electrical domain.

Other features and advantages of the present invention will be set forth in part in the description which follows and the accompanying drawings, wherein the preferred embodiments of the present invention are described and shown, and in part will become apparent to those skilled in art upon examination of the following detailed description taken in conjunction with the accompanying drawings, or may be learned by the practice of the present invention. The advantages of the present invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the present invention will become apparent from the following detailed description of the present invention in which:

Figure 1 is a simplified overview of an exemplary embodiment of an optical cross-connect switching system.

Figure 2 is a first exemplary embodiment of an optical cross-connect switching system of Figure 1.

Figure 3 is an exemplary embodiment of the optical fiber switch matrices forming an optical switch core of Figure 2.

Figure 4 is an exemplary embodiment of mirror arrays forming an optical switch matrix of Figure 3.

Figure 5 is an exemplary embodiment of an I/O subsystem featuring a plurality of I/O port modules.

Figure 6 is an exemplary embodiment of a data path for the transfer of light between I/O port modules and multiple optical switch cores of Figure 2.

Figure 7 is an exemplary embodiment of a control path featuring the interconnections between the I/O port module and servo modules.

Figure 8 is an exemplary embodiment of the I/O port module of Figures 6 and 7 illustrating a data propagation circuit and a control circuit.

Figure 9 is an exemplary embodiment of multiple ports of I/O modules in communication with optical switches controlled by servo modules.

Figure 10 is an exemplary embodiment of an I/O port configured as a test access port.

Figure 11 is an exemplary embodiment of a servo module of the optical cross-connect switching system of Figure 1.

Figure 12 is an exemplary block diagram of a redundant architecture of the optical cross-connect switching system of Figure 1.

Figure 13 is an exemplary block diagram of a system to provide 1+1 fault protection for an exemplary optical network utilizing optical cross-connect switching systems according to one embodiment of the invention.

Figure 14A is an exemplary block diagram of a redundant architecture for an optical cross-connect switching system used in a source node according to one embodiment of the present invention.

Figure 14B is an exemplary block diagram of a redundant architecture for an optical cross-connect switching system used in a source node according to another embodiment of the present invention.

Figure 15A is an exemplary block diagram of an architecture for an optical cross-connect switching system used in an intermediate node according to one embodiment of the present invention.

Figure 15B is an exemplary block diagram of an architecture for an optical cross-connect switching system for use in an intermediate node according to another embodiment of the present invention.

Figure 16A is an exemplary block diagram of an architecture for an optical cross-connect switching system used in a destination node according to one embodiment of the present invention.

Figure 16B is an exemplary block diagram of an architecture for an optical cross-connect switching system used in a destination node according to another embodiment of the present invention.

Figure 17 is an exemplary block diagram of another type of redundant architecture for an optical cross-connect switching system according to one embodiment of the present invention.

Like reference numbers and designations in the drawings indicate like elements providing similar functionality. A letter or prime after a reference number designator represents another or different instance of an element having the reference number designator.

DETAILED DESCRIPTION OF THE INVENTION

Herein, the exemplary embodiments of the present invention relate to a scalable, optical cross-connect switching system. The described embodiments should not limit the scope of the present invention, but rather are intended to provide a thorough understanding of the present invention. Certain well-known circuits are not set forth in detail in order to avoid unnecessarily obscuring the present invention.

In the following description, certain terminology is used to describe various features of the present invention. For example, a "module" includes a substrate normally formed with any type of material or materials upon which components can be attached such as a printed circuit board or a daughter card for example. Examples of a "component" include an optical switch, a processing unit (e.g., Field Programmable Gate Array "FPGA", digital signal processor, general microprocessor, application specific integrated circuit "ASIC", etc.), splitters and the like. A "splitter" is an optical component that performs a bridging operation on an input light signal by splitting that light signal into two or more output light signals. Each module features one or more interfaces to transport information over a link. A "link" is broadly defined as one or more physical or virtual information-carrying mediums that establish a communication pathway such as, for example, optical fiber, electrical wire, cable, bus traces, wireless channels and the like. "Information" can be voice, data, address, and/or control in any representative signaling format such as light signals (e.g., light pulses or photons).

I. General Architectural Overview

Referring to Figure 1, an exemplary embodiment of a simplified overview of an optical cross-connect switching system 100 is shown. Herein, the optical cross-connect switching system 100 comprises three basic units: a switch subsystem 110, a switch control subsystem 120 and an input/output (I/O) subsystem 130. In one embodiment, the modular architecture of the switch subsystem 110, by a method of having

replaceable optical switch cores, provides for switch subsystem maintenance in the event of failure within the switch subsystem 110. It is conceivable that further modularity could be achieved by having replaceable subsections within, thus providing for switch matrix maintenance in the event of failure within a switch matrix itself. The modular architecture of both the switch control subsystem 120 and the I/O subsystem 130, each handling a small number of I/O ports in the system 100, provides scalability to the optical cross-connect switching system 100. Thus, additional I/O ports may be subsequently added to the optical cross-connect switching system 100 by adding or removing input/output (I/O) port modules (described below).

The switch subsystem 110 includes optical switches for routing light signals. In one embodiment, the optical switches forming the switch subsystem 110 are micro-machined mirrors; however, it is contemplated that other switch fabrics may be used such as liquid crystal technology. The I/O subsystem 130 receives external light signals 140 and transfers these signals to the switch subsystem 110. The switch control subsystem 120 controls the configuration of the switch subsystem 110 (e.g., mirror orientation) and performs certain monitoring functions. The interconnectivity between the switch subsystem 110, the switch control subsystem 120 and the I/O subsystem 130 includes redundancy so that no equipment failures would cause complete disablement of the system 100.

Referring now to Figure 2, a first exemplary embodiment of an optical cross-connect switching system 100 is shown. In general, the optical cross-connect switching system 100 is a matrix-based optical cross-connect with associated I/O port modules. More specifically, the optical cross-connect switching system 100 is collectively formed by a plurality of platforms 205, 206 and 207 in communication with each other, although the implementation of the switching system 100 as a single platform is another embodiment. Herein, each platform 205, 206 and 207 includes a frame 210 (e.g., a rack) that physically supports I/O port modules forming the I/O subsystem 130 as well as servo modules, servo control modules and/or network control modules of the

switch control subsystem 120. The modules are arranged either horizontally or vertically within each platform 205, 206 and 207 and can be individually removed or installed without interfering with immediately adjacent modules. In addition, the frame 210 may also physically support one or more optical switch cores, which may also be generally referred to as "switch fabric," of the switch subsystem 110.

As shown in this embodiment, the first platform 205 comprises (i) a plurality of I/O port modules 215 associated with the I/O subsystem 130 of Figure 1, (ii) a plurality of servo modules 225 and a management control subsystem (MCS) 235 associated with switch control subsystem 120 of Figure 1, and (iii) a first (primary) optical switch core 240 associated with switch subsystem 110 of Figure 1. Similarly, the second platform 206 comprises a plurality of additional I/O port modules 245, a plurality of (redundant) servo modules 250, a management control subsystem 255, and a second (redundant) optical switch core 260. The third platform 207 comprises a plurality of servo modules 265 that control various mirrors of the first and second optical switch cores 240 and 260, which correspond to additional ports associated with I/O port modules 245. Additionally, a light path test signal generator(s), a light path signal monitor(s), circuit breakers and/or alarm visual indication 270 may be located within the third platform 207. For clarity, the elements forming the first platform 205 are described since these elements may be found in the second and/or third platforms 206 and 207.

As shown in both Figures 2-4, the first optical switch core 240 includes a first optical switch matrix 241 and a second optical switch matrix 242. These matrices 241 and 242 are collectively positioned to route light signals 250 between a port of a source I/O port module 215_s ("s" is a positive whole number) and a port of a destination I/O port module 215_d ("d" is a positive whole number), both modules located in any of the platforms 205, 206 and 207 as shown in detail in Figure 3. Although a two-bounce routing technique is shown, it is contemplated that other light routing techniques may be used including a three-bounce routing technique in which a second bounce mirror

202 optionally shown in Figure 3 is positioned to assist in routing light signals from one optical switch matrix to another.

As shown in Figure 4, one embodiment for each of the optical switch matrices 241 and 242 includes multiple arrays 300 of micro-machined mirrors. Each mirror (e.g., mirror 310) features a mirrored surface 311 and torsional flexures 320 and 330 that enable the mirror 310 to adjust its physical orientation to reflect incoming light signals in any selected direction. Herein, both the first and second optical switch matrices 241 and 242 include Q micro-machined mirrors, where "Q" is less than or equal to the maximum number of I/O ports that can be supported by the optical cross-connect switching system 100. For this embodiment, "Q" is greater than or equal to 64 but less than or equal to 1152 ($64 \leq Q \leq 1152$). However, the present invention is not limited to any maximum number of mirrors or I/O ports. It is contemplated, however, that the number of mirrors employed within the first and second optical switch matrices 241 and 242 may differ.

As generally shown in Figures 2, 5 and 6, the plurality of I/O port modules 215 features two groups 216 and 217 of I/O port modules. Each group, such as group 216 or 217 for instance, includes up to seventy-two (72) quad-port I/O port modules as shown in Figure 5 that receive power from one or more power supply modules denoted herein as "PSM". The components forming an I/O port module is described below and shown in Figures 8 and 9. Thus, each I/O port module, such as I/O port module 215_s for example, features an external interface 400 for a plurality of I/O ports 410 (e.g., four I/O ports). An I/O port 410 features a duplex socket that is adapted to receive a duplex pair of optical fiber links, one optical fiber link routes a light signal to the I/O port 410 while the other routes light signals from the I/O port 410. This support bi-directional optical connections. There is a small percentage (e.g., less than 15%) of these I/O ports, however, that may be assigned as test access ports as described below.

Moreover, as shown in Figure 6, upon receiving an incoming light signal over an optical fiber link 420, the I/O port module 215_s performs a bridging operation by splitting the incoming light signal into multiple (two or more) bridged light signals for routing to the first and second optical switch cores 240 and 260. The bridged light signals are routed through an internal optical interface 425 featuring optical fiber ribbon links 430 and 440. For this embodiment, the "optical fiber ribbon links" are ribbon cables having multiple optical fiber lines (e.g., two lines from each I/O port). The first optical switch core 240 provides a primary optical path. The second optical switch core 260 provides a redundant optical path in the event the first optical switch core 240 is not operating properly. The optical switch cores 240 and 260 route the bridged light signals to a selected port of a destination I/O port module (e.g., I/O port module 215_d) via optical fiber ribbon links 450 and 460.

Upon receiving light signals from both the first and second optical switch cores 240 and 260, the I/O port module 215_s provides small percentage optical tap signals of the received light paths to the respective servo modules, which in turn determine light signal quality. The respective servo modules will convey light signal quality for each respective light path to the I/O port module, using a digital protocol over an electrical communication link 505 to the I/O port module as shown in Figure 7. The I/O port module 215_s will in turn, determine (i.e. select) which light signal has the higher signal quality and outputs that signal via interface 400. In most cases, the signal quality of the two light paths presented to the I/O port module will be of the same signal quality and may have a relatively low optical loss of approximately seven decibels (7 dB) or less.

Referring now to Figures 2 and 7, each servo module 225 is configured to receive optical tap signals from one or more I/O port modules. Herein, servo module 225_i is configured to receive optical tap signals via link 500 from I/O port module 215_s. These optical tap signals provide feedback to indicate a percentage of the bridged light signals and also allow for light to be injected under certain conditions. In response to receiving optical tap signals via link 500, the servo module 225_i provides mirror control

signals over link 510 to the first optical switch core 240. The mirror control signals are routed via a unique communication path to an optical switch (e.g., a micro-machined mirror) and are associated with the port of the I/O port module 215_s through which the incoming light signal was routed. The mirror control signals are used for proper adjustment of the physical orientation of the mirror.

The I/O port module 215d provides optical tap signals over link 530 to servo module 225_j. In response to receiving the optical tap signals from I/O port module 215_d, the servo module 225_j provides mirror control signals via link 540 to the first optical switch core 240. The mirror control signals are routed via a unique communication path to a micro-machined mirror associated with a selected port of the I/O port module 215_d from which the light signal would be output. Herein, sensing the optical tap (feedback) signals, the servo module 225_j determines the light signal quality and conveys light signal quality information for each light path using a digital protocol over (electrical) link 535. Thereafter, the I/O port module 215d chooses the selected port (i.e. port having the best light signal quality).

Collectively, the optical tap signals, mirror control signals and light signal quality information, which are routed over links 500, 510, 530, 540, 505 and 535, are used by servo modules 225_i and 225_j for adjustment of the physical orientation of mirrors to make a connection between I/O port module 215_s and 215_d.

Additionally, I/O port modules 215_s and 215_d also transfer optical tap signals via links 520 and 550, respectively. Similar to the above description, these optical tap signals establish the redundant optical path by altering the physical orientation of one or more micro-machined mirrors of the second optical switch core 260 using mirror control signals over links 560 and 570 and light signal quality information via links 525 and 555.

In the event that no optical power is presented to the I/O port module 215_s, a substitute light signal may be injected from the servo module 225_i via link 500. An

alignment laser may be used as shown in Figure 11 described below. This process of light substitution allows for connection establishment and verification when no input light is present to the I/O port module 215_s. The substitute light source can be within the same wavelength range (e.g. 1100 nanometers "nm" - 1700 nm) as the allowed input light signal range. In one embodiment, the light source or method of injection would be chosen to not interfere with attached equipment's select operational wavelength range. Choosing a different wavelength source on the servo module and/or a wavelength specific splitter and/or filter on the I/O port module could do this particular embodiment.

The management control subsystem 235 (see Figure 2) enables communications between two or more servo modules placed within the same or different platforms. The management control subsystem 235 includes at least one servo control module 236 and an optional network control module 238. In one embodiment, the servo control module (SCM) 236 ensures communication between at least servo modules 225_i and 225_j that control mirrors associated with the first optical switch core 240. The network control module (NCM) 238 manages the execution of connection configurations for the whole cross-connect switching system and ensures communications between multiple servo control modules 236 and 237. The same architecture is used to control optical switches within the second optical switch core 260 as shown.

II. General Architecture of the I/O Port Modules

Referring now to Figures 8 and 9, an exemplary embodiment of an I/O port module (e.g., I/O port module 215_s) and its communications over optical switch cores 240 and 260 is shown. I/O port module 215_s includes a data propagation circuit 600 for each I/O port and a control circuit 670. Thus, in the event that the I/O port module 215_s is configured with four I/O ports, four data propagation circuits are implemented on the I/O port module 215_s as represented. Only the data propagation circuit 600 for one of

the I/O ports of I/O port module 215_s (e.g., i^{th} I/O port) is shown in detail for clarity sake.

In one embodiment, the data propagation circuit 600 comprises an optical switch 610, a (passive) splitter 620 and a plurality of tap couplers 630_1-630_4. The plurality of tap couplers 630_1-630_4 correspond to the pairs of optical fibers found in optical fibber ribbon links 430 and 440. The control circuit 670 comprises a programmable memory 680, a processing unit 685 and status identification components 690.

As shown, each port of the I/O port module 215_s supports full-duplex communications. Thus, an incoming light signal 606 received over port 605 is routed to the splitter 620. The splitter 620 effectively performs a bridging operation by splitting the incoming light signal 606 into bridged light signals 625, which collectively have the same power level (energy) as the light signal 606. In one embodiment, when the splitter 620 is a 50/50 splitter, the bridged light signals 625 have equal power levels. However, it is contemplated that splitter 620 may produce bridged light signals 625 having disproportionate power levels.

The bridged light signals 625 are routed through the tap couplers 630_1 and 630_2. Attached to servo module 225_i and servo module 225_{i+1} via optical tap links 500 and 520, the tap couplers 630_1 and 630_2 are used to monitor the power level of light signals 635 and 636 propagating through optical fiber ribbon links 430 and 440 (referred to as "outgoing light signals"). This enables the servo modules 225_i and 225_{i+1} to verify the connectivity of the splitter 620 to optical fiber ribbon links 430 and 440 and to detect unacceptable variances in optical performance of the light signal. As shown for this embodiment, the tap couplers 630_1 and 630_2 may separate the bridged light signals into signals having disproportionate power levels in order to maximize the power levels of the outgoing light signals propagating through optical fiber ribbon links 430 and 440. For example, where the tap couplers 630_1 and 630_2 may operate as 90/10 splitters, the

outgoing light signals 635 and 636 have ninety (90%) of the total power level of the bridged light signal while the tap optical signals 640 and 641 have only ten percent (10%).

Referring to Figure 8, tap couplers 630_3 and 630_4 are configured to receive incoming light signal 650 and 655 via optical fiber ribbon links 430 and 440, respectively. The tap couplers 630_3 and 630_4 effectively separate the light signals 650 and 655 into corresponding pairs of light signals having disproportionate power levels (e.g., signals 661, 662 and 663, 664). Signals 662 and 664 having the lower power level are provided to the servo module 225_i and servo module 225_{i+1} via links 500 and 520 for monitoring the power levels of the light signals 661 and 663, without the light signals 661 and 663 experiencing substantial signal degradation. The signals 662 and 664 may be light signals that undergo O/E conversion at the I/O port module 215_s or at the servo modules 225_i and 225_{i+1} as shown in Figure 11. The tap couplers 630_3 and 630_4 are shown as 90/10 splitters; however, tap couplers 630_3 and 630_4 may be any selected ratio, including 50/50.

The light signals 661 and 663 are routed to the optical switch 610 of a destined I/O port. The control circuit 650 on the I/O port module 215_s determines which of the pair of light signals 661 and 663 has the best signal quality based on conveyed light signal quality information from the servo modules via links 505 and 525 as briefly described below. Parameters used to determine light signal quality include measured optical signal intensity/power, extinction ratio, and the like. The light signal quality information to the I/O port module may be conveyed as failed due to the servo module service operations, high bit error rate, an external light path has failed, and the like. The light signal 661 or 663 with the best signal quality is output through the I/O port 605. Of course, it is contemplated that the light signal output operations described for I/O port i are applicable to I/O port j as shown.

It is contemplated that an I/O port of the I/O port module 215_s may be configured as a test access port. A "test access port" is an I/O port that is used for monitoring light signals routed through another port. Normally, the test access port receives a portion of the power level of a light signal routed through a selected optical switch (e.g., micro-machined mirror). For example, as shown in Figure 10, an I/O port 218 of the I/O port module 215_s is configured for coupling with a monitoring device 219 (e.g., a bit error rate "BER" monitor in combination with an optical-electrical "O/E" converter, etc.) to monitor a power level of a light signal routed to the i^{th} I/O port from an optical switch.

Referring back to Figure 8, the control circuit 670 comprises the programmable memory 680 in communication with the processing unit 685 (e.g., FPGA). The programmable memory 680 contains software and other information used by the processing unit 685 to provide selection of the best quality signal based on digital electrical signaling from servo module 225_i and servo module 225_{i+1} over links 505 and 525, respectively. Also, programmable memory 680 includes information used by the processing unit 685 to control the state of the status identification components 690 (e.g., light emitting diodes "LEDs"). The state of the status identification components 690 identifies (1) whether each I/O port is operational and/or (2) whether the I/O port module is operational. The processing unit 685 is further in communications with optical switches of each data propagation circuit employed in the I/O port module 215_s in order to receive switch status signals and provide switch control signals. As shown for clarity, processing unit 685 provides optical switch 610 with switch control signals for receiving switch status signals and selecting either light signal 661 or light signal 663.

III. <u>General Architecture of the Servo Modules</u>

Referring now to Figure 11, an exemplary embodiment of the servo module (e.g., servo module 225_i) is shown. In one embodiment, the servo module 225_i comprises two

separate modules in communication over connectors 705 and 790. These separate modules are referred to as an "optical detector module" 700 and a "servo mirror control module" 750.

The optical detector module 700 comprises a first processing unit 710, memory 715, a plurality of detection/modulation (DM) circuits 716 and status identification components 717. As shown, the optical detector module 700 features sixteen (16) DM circuits 716 to support four (4) quad-port I/O port modules. Each DM circuit 716 includes an analog-to-digital (A/D) converter 720, a laser 725, optical-electrical (O/E) detectors 730 and 731, and optional amplifiers 735 and 736.

The servo mirror control module 750 comprises a second processing unit 755, a memory 760, a plurality of mirror signal detection and generation (SDG) circuits 761, a third processing unit 775 and status identification components 795. The SDG circuits 761 correspond in number to the DM circuits 716 of the optical detector module 700. Each SDG circuit 761 features an A/D converter 765, a digital-to-analog (D/A) converter 770, hinge position sensors 780-781 and high voltage (HV) mirror drivers 785-786.

As shown in Figure 11, the optical detector module 700 is removably coupled to the servo mirror control module 750. This allows the optical detector module 700 to be "hot swapped" from a backplane, which features connectors 705 and 790 connecting the optical detector module 700 to the servo mirror control module 750, without disrupting the servo mirror control module's 750 ability to hold the mirrors in their existing positions for an extended period of time. This "hot swapping" of the optical detector module 700 allows for repair or upgrade of the optical detector module 700. Optical detector module 700 receives optical tap (feedback) signals 640 and 662 from one or more I/O port modules (e.g., I/O port module 215_5 via link 500) and can transmit optical control signals 726 from the laser 725 for alignment of light signals transferred between two I/O port modules. The optical tap signal 640 is based on an input light signal that is routed to the switch fabric.

More specifically, with respect to servo module 225_i, the O/E detectors 730 and 731 are coupled to tap couplers 630_1 and 630_3 of Figures 8-9. More specifically, the O/E detectors 730 and 731 are configured to detect incoming, optical tap signals 640 and 662, convert the optical tap signals 640 and 662 into corresponding electrical control signals measuring a power level of the outgoing light signal, and optionally route the electrical control signals to corresponding amplifiers 735 and 736. The (amplified) electrical control signals are provided to the A/D converter 720. The A/D converter 720 converts the electrical control signals into measured power sense signals 644 of a digital form. The measured power sense signals 644 are provided to the first processing unit 710.

Herein, the first processing unit 710 may perform a number of operations based on the electrical control signals such as threshold crossing, LOS integration, input/output power ratio analysis and the like. Software and other information necessary for performing these operations may be obtained from the memory 715 by the first processing unit 710. Herein, memory 715 can be non-volatile memory such as non-volatile random access memory, electrically erasable programmable read only memory (EEPROM) and the like.

The optical detector module 700 includes multiple status identification components 717 (e.g., light emitting diodes "LEDs"). A first LED 718 identifies whether any operational faults associated with the servo module 225_i have occurred. A second LED 719 indicates when the optical detector module 700 is in service.

Referring still to Figure 11, in this embodiment, the servo mirror control module 750 comprises the second processing unit 755 that is coupled to both the first processing unit 710 and the third processing unit 775. For instance, in order to adjust the switch fabric in response to the measured power sense signals 644, the second processing unit 755 receives information representative of the measured power sense signals from the first processing unit 710 via connectors 705 and 790. The second

processing unit 755 further receives information representative of measured power sense signals for the light signal at a targeted I/O port. This information is provided by the SCM 236 over link 580 via the third processing unit 775. This assists in reducing errors in adjusting the torsional flexures of the mirrors.

Upon receipt of these measured power readings, the second processing unit 755 controls a particular SDG circuit corresponding to a mirror associated with the I/O port over which the tapped light signal was routed. The control involves slight mirror orientation adjustments if the power level readings differ substantially.

In particular, a first hinge position sensor 780 senses a position of a mirror via link 510 from the first optical switch core 240. The sensed position signal is routed to the A/D converter 765, which is subsequently placed in a digital format before routing to the second processing unit 755. When the servo module 225_i is adjusting the switch fabric, the second processing unit 755 transfers mirror control signals to the D/A converter 770. The mirror control signals are routed to HV driver 785 and applied to a selected mirror of the first optical switch core in order to adjust the amount of torsional flexure along a first dimensional plane (e.g., X-axis). This is accomplished to minimize the loss experienced by the light signal.

A second hinge position sensor 781 senses a position of a mirror for the first optical switch core along a second dimensional plane (e.g., Y-axis). The sensed position signal is routed to the A/D converter 765, which is subsequently placed in a digital format before routing to the second processing unit 755. When the servo module 225_i is adjusting the switch fabric, the second processing unit 755 transfers mirror control signals to the D/A converter 770. The mirror control signals are routed to HV driver 786 and are applied to the selected mirror of the first optical switch core in order to adjust the amount of torsional flexure along the second dimensional plane. The specifics of the hinge position sensors 780 and 781 are described in a recently published PCT application entitled "Micromachined Members Coupled for Relative

Rotation By Torsional Flexure Hinges" (International Publication No. WO 00/13210) published on or around March 9, 2000.

In another embodiment, when I/O port module 215_s is the destination of a light signal, the second processing unit 755 receives information representative of the measured power sense signals associated with the optical tap signal 662 that has been analyzed by the first processing unit 710. The optical tap signal 662 is based on an output light signal being routed from an I/O port. In this situation, the third processing unit 775 receives information associated with the measured power sense signals from a source I/O port as reported by SCM 236 over link 580.

IV. Redundant Architecture of the Optical Cross-Connect Switching System

Referring now to Figure 12, a block diagram of an alternative embodiment of the architecture of the optical cross-connect switching system of Figure 1 is shown which includes redundant protection capabilities. Redundancy is desired in order to increase the reliability of such an optical cross-connect switching system. Aside from the I/O port modules, all other modules are duplicated to obtain the desired redundancy. Thus, it is necessary for light signals from a source I/O port module 215_s to be routed to a destination I/O port module 215_d through two optical paths, namely a primary optical path 800 using a first optical switch core 240 and a redundant optical path 810 using a second optical switch core 260.

With respect to the primary optical path 800, a servo module 225_i is connected to both the source I/O port module 215_s and the first optical switch matrix (not shown) of the first optical switch core 240. In particular, the servo module 225_i controls the physical orientation of a mirror of the first optical switch matrix that corresponds to the source I/O port module 215_s. To establish and maintain the primary optical path 800 for the light signal, the servo module 225_i needs to communicate with other servo modules such as servo module 225_j. Thus, a servo control module (SCM) is

implemented to support such communications, possibly through a time-slot switching arrangement.

As shown, the SCMs 236_1-236_2 are also duplicated so that each servo module 225 is connected to at least two SCMs 236_1-236_2. Thus, in the event that the SCM 236_1 fails, the primary optical path 800 remains intact because communications between the servo modules 225_i and 225_j are maintained via redundant SCM 237_1. The transfer is accomplished by temporarily halting the adjustment of (i.e. freezing) the mirrors inside the first optical switch core 240 while control is transferred from SCM 236_1 to SCM 237_1. The SCMs 236_1 and 237_1 associated with the first optical switch core 240 are in communication via a network control modules (NCMs) 238_1 and 238_2 for example.

With respect to the redundant optical path 810, a servo module 225_{i+1} is connected to both the source I/O port module 215_s and one or more mirror(s) of a first optical switch matrix (not shown) of the second optical switch core 260. Another servo module 225_{j+1} is connected to both the destination I/O port module 215_d and one or more mirror(s) of a second optical switch matrix (not shown) of the second optical switch core 260. The orientation of these mirrors produces the redundant optical path 810.

To establish and maintain the redundant optical path 810 for the light signal, a SCM 236_2 may be implemented with a dedicated time-slot switching arrangement in order to support continuous communications between the servo module and another redundant servo module associated with the destination I/O port module. As shown, the SCM 236_2 is also duplicated so that each servo module 225_{i+1} and 225_{j+1} is connected to at least two SCMs 236_2 and 237_2. Thus, the redundant optical path 810 is maintained even when one of the SCMs 236_2 and 237_2 fails. The SCMs 236_2 and 237_2 associated with the second optical switch core 260 communicate via the first NCM 238_1 and the second NCM 238_2, respectively. The second NCM 238_2 is in communication with the first NCM 238_1 to allow all SCMs and servo modules to

communicate for coordination of the primary optical path 800 and the redundant optical path 810.

V. 1+1 Fault Protection In A Network Of Optical Cross-Connect Switching Systems

The present invention provides methods, systems, and data communication networks for providing fault protection in an optical network. Particularly, the present invention provides 1+1 optical fault protection in an optical network utilizing optical cross-connect switching systems. In 1+1 fault protection, traffic is transmitted simultaneously on two separate fibers (usually over disjoint routes) from a source node to a destination node. Generally, one fiber is termed the working fiber and the other fiber is termed the protection fiber. The destination node typically selects one of the two fibers for reception. If that fiber is cut, the destination node simply switches over to the other fiber (e.g. the protected fiber) and continues to receive data. This form a protection is very fast and requires no signaling protocol between the two ends.

Figure 13 illustrates an exemplary block diagram of a system to provide 1+1 fault protection for an exemplary optical network utilizing optical cross-connect switching systems according to one embodiment of the invention. As shown in Figure 13, a source node 1302 may be attached to client equipment 1303, such as an IP router, which provides an input optical signal 1304 to the source node 1302. The source node 1302 includes an optical cross-connect switching system 1305. The optical cross-connect switching system 1305 has a splitter 1306 that splits the input optical signal 1304 into two similar optical signals 1310 and 1312. The two similar optical signals 1310 and 1312 contain the same information as the original input optical signal 1304. The two similar optical signals 1310 and 1312 are diversely routed through the optical network 1316 from the source node 1302 to two adjacent intermediate nodes 1318 and 1320, respectively, along two separate fiber optic cables 1322 and 1324 (e.g. a working fiber and a protected fiber), respectively. The intermediate nodes 1318 and 1320 also

contain optical cross-connect switching systems 1328 and 1330, respectively. Thus, the two similar optical signals are routed along a primary optical path 1332 and a redundant optical path 1334 through the optical network 1316.

The intermediate nodes 1318 and 1320 continue routing the two similar optical signals along the primary optical path 1332 and the redundant optical path 1334 to a destination node 1340. The destination node 1340 similarly has an optical cross-connect switching system 1342. The destination node 1340 receives the two similar optical signals 1310 and 1312 and utilizes a selector switch 1344 to select one of the available two similar optical signals 1310 and 1312. Therefore, if one of the diversely routed similar optical signals 1310 and 1312 fails to reach the destination node 1340, due to, for example, a fault in the optical network, the other one of the similar optical signals is still available to the destination node 1340. Thus, even if one of the primary or redundant optical paths 1332 or 1334 paths fails, caused by, for example, a fiber optic cable being cut or an intermediate node failing, the other one of the similar optical signals will still be transmitted to the destination node 1340. Accordingly, the same information is still provided to the destination node 1340 and 1+1 optical fault protection is provided for the optical network 1316. Further, client equipment 1345, such as an IP router, may be attached to the destination node for receipt of the optical signal.

Accordingly, the present invention provides an optical, scalable cross-connect system with a variety features such as redundancy for fault protection and rapid restoration that can be used to implement 1+1 fault protection in an optical network. Further, it should be appreciated that the optical network 1316 is only exemplary and that the present invention can be used with a wide variety of different types of optical networks. For example, the optical network may include many more intermediate nodes then shown in Figure 13. It should be noted that the following discussions of architectures for optical cross-connect switching systems for source, intermediate, and destination nodes, which can be used in an optical network, utilize the same basic

architectures of the general optical cross-connect switching system previously described, with minor variations, to accomplish the function of the source, intermediate, or destination node.

Referring now to Figure 14A, a block diagram of a redundant architecture for an optical cross-connect switching system used in a source node is shown according to one embodiment of the present invention. Aside from the I/O port modules/cards, all other modules are duplicated to obtain the desired redundancy. As shown in Figure 14A, client equipment 1303 may be attached to the source node 1302 which includes a source optical cross-connect switching system 1405 according to one embodiment of the present invention. The client equipment 1303, such as an IP router, generates an input optical signal 1304 that is inputted to the source node 1302. Generally, the input optical signal 1304 is first routed through a source I/O port module/card 215_s having a splitter 1404 which splits the input optical signal 1304 into two similar optical signals 1310 and 1312. The two similar optical signals contain the same information. It should be appreciated that the source I/O port card 215_s is a smart port card and has been previously described with reference to Figures 8 and 9. Particularly, the splitter 1404 corresponds to the splitter 620 (previously described) which effectively performs a bridging operation by splitting the input optical signal 1304 into the two similar optical signals 1310 and 1312 that collectively have the same power level (energy) as the original input optical signal 1304. In one embodiment, when the splitter 1404 is a 50/50 splitter, the bridged light signals 1310 and 1312 have equal power levels. However, it is contemplated that splitter 1404 may produce bridged light signals 1310 and 1312 having disproportionate power levels.

Moreover, the input optical signal 1304 is split into two similar optical signals 1310 and 1312 that follow a primary optical path 1410 and a redundant optical path 1412, respectively, through the source node 1302. The two similar optical signals 1310 and 1312 are switched by a source optical switching device 1413 that includes a first optical switch core 240 and a second optical switch core 260. The first of the two

similar optical signals, which follows the primary optical path 1410, is switched by the first optical switch core 240 to a first destination I/O port module/card 1416. The first destination I/O port card 1416 then transmits the first similar optical signal 1310 to an adjacent intermediate node along a primary optical path of the overall optical network (e.g. along a working fiber) (Fig. 13). Similarly, the second of the two similar optical signals, which follows the redundant optical path 1412, is switched by the second optical switch core 260 to a second destination I/O port module/card 1418. The second destination I/O port card 1418 then transmits the second similar optical signal 1312 to an adjacent intermediate node along a redundant optical path (e.g. along a protected fiber) such that the two similar optical signals are diversely routed through the optical network (Fig. 13). It should be noted that first and second destination I/O port cards 1416 and 1418 can be passive port cards or can be similar to the destination I/O port module/card 215_d previously described with reference to Figures 8 and 9. Furthermore, the first and second destination I/O port cards 1416 and 1418 can be smart cards having a selector switch set to a predefined position to select one of the similar optical signals. Also, it should be noted that the first and second optical switch cores 240 and 260 both include a plurality of optical switches to accomplish switching as has been previously described.

By splitting the input optical signal 1304 into two similar optical signals 1310 and 1312 that contain the same information as the original input optical signal and diversely routing them through the source node along primary and redundant optical paths 1410 or 1412, if one of the primary or redundant optical paths 1410 or 1412 fails (e.g. due to one of the optical switch cores failing), the other similar optical signal traveling along the other path will still transmitted through the source node. Thus, 1+1 optical fault protection is thereby provided within the source node itself.

With respect to the primary optical path 1410, a servo module 225_i is connected to both the source I/O port module 215_s and the mirrors of the first optical switch matrix (not shown) of the first optical switch core 240. In particular, the servo module

225_i controls the physical orientation of at least one mirror of the first optical switch matrix that corresponds to the source I/O port module 215_s. Servo module 225_j is connected to the destination I/O port card 1416 and the mirrors of a second optical switch matrix (not shown) of the first optical switch core 240. In particular, the servo module 225j controls the physical orientation of at least one mirror of the second optical switch matrix that corresponds to the destination I/O port card 1416. The orientation of these mirrors produces the primary optical path 1410. To establish and maintain the primary optical path 1410 for the light signal, the servo module 225_i needs to communicate with other servo modules such as servo module 225_j. Thus, a servo control module (SCM) 236_1 is implemented to support such communications, possibly through a time-slot switching arrangement.

As shown in Figure 14A, SCM 236_1 is duplicated with SCM 237_1 so that each servo module 225_i and 225_j is connected to at least two SCMs 236_1 and 237_1. Thus, in the event that SCM 236_1 fails, the primary optical path 1410 remains intact because communications between the servo modules 225_i and 225_j are maintained via redundant SCM 237_1. The transfer is accomplished by temporarily halting the adjustment of (i.e. freezing) the mirrors inside the first optical switch core 240 while control is transferred from SCM 236_1 to SCM 237_1. The SCMs 236_1 and 237_1 associated with the first optical switch core 240 are in communication via network control modules (NCMs) 238_1 and 238_2 for example.

With respect to the redundant optical path 1412, a servo module 225_{i+1} is connected to both the source I/O port module 215_s and the mirrors of a first optical switch matrix (not shown) of the second optical switch core 260. In particular, the servo module 225_{i+1} controls the physical orientation of at least one mirror of the first optical switch matrix that corresponds to the source I/O port module 215_s. Another servo module 225_{j+1} is connected to both the destination I/O port card 1418 and the mirrors of a second optical switch matrix (not shown) of the second optical switch core 260. In particular, the servo module 225_{j+1} controls the physical orientation of at least

one mirror of the second optical switch matrix that corresponds to the destination I/O port card 1418. The orientation of these mirrors produces the redundant optical path 1412.

To establish and maintain the redundant optical path 1412 for the light signal, an SCM 236_2 may be implemented with a dedicated time-slot switching arrangement in order to support continuous communications between the servo module 225_{i+1} and the other servo module 225_{j+1}. As shown, the SCM 236_2 is duplicated with SCM 237_2 so that each servo module 225_{i+1} and 225_{j+1} is connected to at least two SCMs 236_2 and 237_2. Thus, the redundant optical path 1412 is maintained even when one of the SCMs 236_2 and 237_2 fails. The SCMs 236_2 and 237_2 associated with the second optical switch core 260 communicate via the first NCM 238_1 and the second NCM 238_2, respectively. The second NCM 238_2 is in communication with the first NCM 238_1 to allow all SCMs and servo modules to communicate for coordination of the primary optical path 1410 and the redundant optical path 1412.

Referring now to Figure 14B, a block diagram of a redundant architecture for an optical cross-connect switching system used in a source node is shown according to another embodiment of the present invention. Aside from the I/O port modules/cards, all other modules are duplicated to obtain the desired redundancy. As shown in Figure 14B, client equipment 1303 may be attached to the source node 1302 which includes a source optical cross-connect switching system 1420 according another embodiment of the present invention. The client equipment 1303, such as an IP router, generates an input optical signal 1304 that is inputted to the source node 1302. Generally, the input optical signal 1304 is first routed through a source I/O port module/card 215_s having a splitter 1404 which splits the input optical signal 1304 into two similar optical signals 1310 and 1312. The two similar optical signals contain the same information. It should be appreciated that the source I/O port card 215_s is a smart port card and has been previously described with reference to Figures 8 and 9. Particularly, the splitter 1404 corresponds to the splitter 620 (previously described) which effectively performs

a bridging operation by splitting the input optical signal 1304 into the two similar optical signals 1310 and 1312 that collectively have the same power level (energy) as the original input optical signal 1304. In one embodiment, when the splitter 1404 is a 50/50 splitter, the bridged light signals 1310 and 1312 have equal power levels. However, it is contemplated that splitter 1404 may produce bridged light signals 1310 and 1312 having disproportionate power levels.

Moreover, the input optical signal 1304 is split into two similar optical signals 1310 and 1312 that follow a primary optical path 1410 and a redundant optical path 1412, respectively, through the source node 1302. The two similar optical signals 1310 and 1312 are switched by a source optical switching device 1415 that includes a first optical switch core 240. Both the first and second similar optical signals, following the primary and redundant optical paths 1410 and 1412, respectively, are switched by the first optical switch core 240 to a first destination I/O port card 1416 and a second destination I/O port card 1418, respectively. The first destination I/O port card 1416 then transmits the first similar optical signal 1310 to an adjacent intermediate node along a primary optical path of the overall optical network (e.g. along a working fiber) (Fig. 13). Similarly, the second of the two similar optical signals, which follows the redundant optical path 1412, is switched by the second optical switch core 260 to a second destination I/O port module/card 1418. The second destination I/O port card 1418 then transmits the second similar optical signal 1312 to an adjacent intermediate node along a redundant optical path (e.g. along a protected fiber) such that the two similar optical signals are diversely routed through the optical network (Fig. 13). It should be noted that first and second destination I/O port cards 1416 and 1418 can be passive port cards or can be similar to the destination I/O port module/card 215_d previously described with reference to Figures 8 and 9. Furthermore, the first and second destination I/O port cards 1416 and 1418 can be smart cards having a selector switch set to a predefined position to select one of the similar optical signals. Also, it should be noted that the first optical switch core 240 and the second optical switch core

260 both include a plurality of optical switches to accomplish switching as has been previously described.

By splitting the input optical signal 1304 into two similar optical signals 1310 and 1312 that contain the same information as the original input optical signal and diversely routing them through the source node along primary and redundant optical paths 1410 or 1412, if one of the primary or redundant optical paths 1410 or 1412 fails (e.g. due to one of the mirrors failing), the other similar optical signal traveling along the other path will still transmitted through the source node. Thus, 1+1 optical fault protection is thereby provided within the source node itself. Also, this embodiment takes advantage of the reliability of the optical switch core 240 by using only one optical switch core 240, thereby eliminating parts and costs to the overall optical-cross connect switching system 1420.

With respect to the both the primary and redundant optical paths 1410 and 1412, a servo module 225_i is connected to both the source I/O port module 215_s and the mirrors of the first optical switch matrix (not shown) of the first optical switch core 240. In particular, the servo module 225_i controls the physical orientations of the mirrors of the first optical switch matrix that correspond to the source I/O port module 215_s for routing both the primary and the redundant optical paths 1410 and 1412. Servo module 225_j is connected to the destination I/O port cards 1416 and 1418 and the mirrors of a second optical switch matrix (not shown) of the first optical switch core 240 for routing both the primary and the redundant optical paths 1410 and 1412. The orientations of the mirrors produce the primary and redundant optical paths 1410 and 1412, respectively. To establish and maintain the primary and the redundant optical paths 1410 and 1412, the servo module 225_i needs to communicate with other servo modules such as servo module 225_j. Thus, a servo control module (SCM) 236_1 is implemented to support such communications, possibly through a time-slot switching arrangement.

As shown, the SCM 236_1 is duplicated with redundant SCM 237_1 so that servo modules $225_{i \text{ and } j}$ are connected to at least two SCMs 236_1 and 237_1. Thus, in the event that the SCM 236_1 fails, the primary and redundant optical paths 1410 and 1412 remain intact because communications between the servo modules 225_i and 225_j are maintained via redundant SCM 237_1. The transfer is accomplished by temporarily halting the adjustment of (i.e. freezing) the mirrors inside the first optical switch core 240 while control is transferred from SCM 236_1 to SCM 237_1. The SCMs 236_1 and 237_1 associated with the first optical switch core 240 are in communication via network control modules (NCMs) 238_1 and 238_2 for example. Thus, 1+1 optical fault protection can be provided within the source node itself.

Various embodiments of architectures for optical cross-connect switching systems for other source, intermediate, and destination nodes will now be discussed utilizing either a single optical switch core (e.g. just the first optical switch core 240) or two optical switch cores (e.g. the first and second optical switch cores 240 and 260). It should be appreciated to those skilled in the art that the previous discussion with reference to Figures 14A and 14B regarding the operation of the servo modules and redundant servo modules 225, the servo control modules 236 (SCMs), the redundant servo control modules 237 (SCMs), and the network control modules 238 (NCMs), to control mirror orientations for setting primary and redundant optical paths, as well as internal optical cross-connect switching system redundancies, for both the one and two optical switch core cases, can be applied to the optical cross-connect switching systems for the other source, intermediate, and destination nodes that will now be discussed. Therefore, the discussion of these features has been left out for the sake of brevity. It is readily apparent that these features can be easily applied to the following optical cross-connect switching systems for other source, intermediate, and destination nodes based upon the previous discussions of Figures 14A and 14B.

Referring now to Figure 15A, a block diagram of an architecture for an optical cross-connect switching system used in an intermediate node is shown according to one

embodiment of the present invention. Basically, the intermediate optical cross-connect switching system 1502 of the intermediate node 1318 receives one of the two similar optical signals 1310 or 1312 from a source node or a prior intermediate node and routes it to another intermediate node or a destination node. Particularly, a source I/O port module/card 1506 receives the similar optical signal. The source I/O port card 1506 can be a passive port card or a smart port card. The similar optical signal is switched by an intermediate optical switching device 1503 that includes a first optical switch core 240. The first optical switch core 240 switches the received similar optical signal to a destination I/O port module/card 1508. As previously discussed, the first optical switch core 240 includes a plurality of optical switches to accomplish switching. The destination I/O port card 1508 can be a passive port card or can be similar to the destination I/O port card 215_d previously described with reference to Figures 8 and 9 (e.g. such as a smart port card). The destination I/O port card 1508 then transmits the received similar optical signal 1310 or 1312 to an adjacent intermediate or destination node along one of the primary or redundant optical paths (e.g. along a working or protected fiber) of the overall optical network such that the received similar optical signal 1310 or 1312 continues to be diversely routed through the optical network (Fig. 13).

Referring now to Figure 15B, a block diagram of an architecture for an optical cross-connect switching system for use in an intermediate node is shown according to another embodiment of the present invention. Basically, the intermediate optical cross-connect switching system 1510 receives one of the two similar optical signals 1310 or 1312 from a source node or a prior intermediate node and routes it to another intermediate node or a destination node. This embodiment also provides 1+1 optical fault protection within the intermediate node 1318 itself.

Particularly, a source I/O port module/card 1512 receives one of the similar optical signals 1310 or 1312. The source I/O port card 1512 has a splitter 1514 that splits the received similar optical signal into two split optical signals 1518 and 1520.

The two split signals 1518 and 1520 contain the same information as the received similar optical signal 1310 or 1312. It should be appreciated that the source I/O port card 1512 is a smart port card, analogous to the source I/O port card 215_5, and has been previously described with reference to Figures 8, 9, and 14. Particularly, the splitter 1404 corresponds to the splitter 620 (previously described) which effectively performs a bridging operation by splitting the received similar optical signal into the two split optical signals 1518 and 1520 that collectively have the same power level (energy) as the original received similar optical signal 1310 or 1312.

Moreover, the received similar optical signal 1310 or 1312 is split into two split optical signals 1518 and 1520 that follow a primary optical path 1524 and a redundant optical path 1526, respectively, through the intermediate node 1318. The two split optical signals 1518 and 1520 are switched by an intermediate optical switching device 1505 that includes a first optical switch core 240 and a second optical switch core 260. The first of the two split optical signals 1518, which follows the primary optical path 1524, is switched by the first optical switch core 240 to a destination I/O port module/card 1530. Similarly, the second of the two split optical signals 1520, which follows the redundant optical path 1526, is switched by the second optical switch core 260 to the destination I/O port card 1530. The destination I/O port card 1530 includes a selector switch 1532 to select one of the two split optical signals 1518 or 1520 such that if one of the diversely routed split optical signals fails within the optical cross-connect switching system of the intermediate node the other one of the two split optical signals 1518 or 1520 corresponding to the received similar optical signal 1310 or 1312 can still be used for routing through the optical network to another intermediate node or a destination node. The destination I/O port card 1530 transmits the selected split optical signal to an adjacent intermediate or destination node along one of the primary or redundant optical paths (e.g. along a working or protected fiber) of the overall optical network (Fig. 13). Thus, the information within the optical signal of the received

similar optical signal 1310 or 1312 continues to be diversely routed through the optical network.

It should be noted that destination I/O port card 1530 can be similar to the destination I/O port card 215_d previously described with reference to Figures 8, 9 and 12. Particularly, the two split optical signals 1518 and 1520 can be routed to the optical switch 610 of destination I/O port card 215_d. The split optical signal 1518 or 1520 with the best signal quality is output through destination I/O port card 1530. Also, it should be noted that the first and second optical switch cores 240 and 260 both include a plurality of optical switches to accomplish switching as has been previously described.

By splitting the received similar optical signal 1310 or 1312 into two split optical signals 1518 and 1520 and diversely routing them through the intermediate node along primary and redundant optical paths 1524 and 1526, if one of the primary or redundant optical paths fails (e.g. due to one of the optical switch cores failing), the other split optical signal traveling along the other path will still transmitted through the intermediate node. Thus, 1+1 optical fault protection is thereby provided within the intermediate node itself.

Referring now to Figure 16A, a block diagram of an architecture for an optical cross-connect switching system used in a destination node is shown according to one embodiment of the present invention. As shown in Figure 16A, client equipment 1345 may be attached to the destination node 1340 which includes a destination optical cross-connect switching system 1602 according to an embodiment of the present invention. The client equipment1345, such as an IP router, receives one of the two similar optical signals 1310 or 1312 that have been diversely routed through the optical network, both of which contain the same information as the original input optical signal 1304 (Fig. 13).

Basically, the two similar optical signals 1310 and 1312 are each received and routed through first and second source I/O port module/cards 1606 and 1608,

respectively. It should be noted that first and second source I/O port cards 1606 and 1608 can be passive port cards or can be similar to the source I/O port module/card 215_s previously described with reference to Figures 8 and 9. Furthermore, the first and second source I/O port cards 1606 and 1608 can be smart cards having a selector switch set to a predefined position to select the similar optical signal.

Moreover, the two similar optical signals 1310 and 1312 are transmitted along a first optical path and second optical path 1610 and 1612, respectively, through the destination node 1340. The two similar optical signals 1310 and 1312 are switched by a destination optical switching device 1614 that includes a first optical switch core 240. Both the first and second similar optical signals 1310 or 1312, following the first and second optical paths 1610 and 1612, respectively, are switched by the first optical switch core 240 to a destination I/O port module/card 1618. The destination I/O port card 1618 includes a selector switch 1620 to select one of the two similar optical signals 1310 or 1312 such that if one of the two similar optical signals fails within the optical cross-connect switching system 1602 of the destination node 1340 the other one of the similar optical signals can still be used for transmitting through the destination node 1340. The destination I/O port card 1618 then transmits the selected similar optical signal 1310 or 1312 to the attached client equipment 1345.

It should be noted that destination I/O port card 1618 can be similar to the destination I/O port card 215_d previously described with reference to Figures 8, 9 and 12. Particularly, the two similar optical signals 1310 and 1312 can be routed to the optical switch 610 of destination I/O port card 215_d. The similar optical signal 1310 or 1312 with the best signal quality is output through destination I/O port card 1618 to the client equipment. Also, it should be noted that the first switch core 240 includes a plurality of optical switches to accomplish switching as has been previously described.

If one of the diversely routed similar optical signals 1310 and 1312 fails to reach the destination node 1340, due to, for example, a fault in the optical network, the

other one of the similar optical signals 1310 and 1312 is still available for routing through destination node 1340 to the attached client equipment 1345. Referring also to Figure 13, even if one of the primary or redundant optical paths 1332 and 1334 of the optical network 1316 fails, caused by, for example, a fiber optic cable being cut or an intermediate node failing, the other one of the similar optical signals 1310 or 1312 will still be transmitted to the destination node 1340 and to the attached client equipment 1345. Accordingly, the same information from the original input optical signal 1304 received at the source node 1302 is still provided to the destination node 1340 and 1+1 optical fault protection is provided for the optical network.

Moreover, because the received similar optical signals 1310 and 1312 are diversely routed through the destination node along the first and second optical paths 1610 and 1612, respectively, if one of the first or second paths fails (e.g. due to a mirror failing) within the optical cross-connect switching system 1602 of the destination node 1340, the other similar optical signal traveling the other path is still available to the destination I/O port card 1618 and the client equipment 1345. Thus, 1+1 optical fault protection is thereby provided within the destination node itself. Also, this embodiment takes advantage of the reliability of the optical switch core 240 by using only one optical switch core 240, thereby eliminating parts and costs to the overall optical-cross connect switching system 1602.

Referring now to Figure 16B, a block diagram of an architecture for an optical cross-connect switching system used in a destination node is shown according to another embodiment of the present invention. As shown in Figure 16B, client equipment 1345 may be attached to the destination node 1340 which includes a destination optical cross-connect switching system 1632 according to another embodiment of the present invention. The client equipment1345, such as an IP router, receives one of the two similar optical signals 1310 or 1312 that have been diversely routed through the optical network, both of which contain the same information as the original input optical signal 1304 (Fig. 13).

Basically, the two similar optical signals 1310 and 1312 are each received and routed through first and second source I/O port module/cards 1636 and 1638, respectively. It should be noted that first and second source I/O port cards 1636 and 1638 can be passive port cards or can be similar to the source I/O port module/card 215_s previously described with reference to Figures 8 and 9. Furthermore, the first and second source I/O port cards 1636 and 1638 can be smart cards having a selector switch set to a predefined position to select the similar optical signal.

Moreover, the two similar optical signals 1310 and 1312 are transmitted along a first optical path and a second optical path 1642 and 1644, respectively, through the destination node 1340. The two similar optical signals 1310 and 1312 are switched by a destination optical switching device 1646 that includes a first optical switch core 240 and a second optical switch core 260. The first of the two similar optical signals, which follows the first optical path 1642, is switched by the first optical switch core 240 to a destination I/O port module/card 1650. Similarly, the second of the two similar optical signals, which follows the second optical path 1644, is switched by the second optical switch core 260 to the destination I/O port card 1650. The destination I/O port card 1650 includes a selector switch 1652 to select one of the two similar optical signals 1310 or 1312 such that if one of the two similar optical signals fails within the optical cross-connect switching system 1632 of the destination node 1340 the other one of the similar optical signals can still be used for transmitting through the destination node 1340. The destination I/O port card 1650 then transmits the selected similar optical signal 1310 or 1312 to the attached client equipment 1345.

It should be noted that destination I/O port card 1650 can be similar to the destination I/O port card 215_d previously described with reference to Figures 8, 9 and 12. Particularly, the two similar optical signals 1310 and 1312 can be routed to the optical switch 610 of destination I/O port card 215_d. The similar optical signal 1310 or 1312 with the best signal quality is output through destination I/O port card 1650 to the client equipment 1345. Also, it should be noted that the first switch core 240 and the

second switch core 260 each include a plurality of optical switches to accomplish switching as has been previously described.

If one of the diversely routed similar optical signals 1310 and 1312 fails to reach the destination node 1340, due to, for example, a fault in the optical network, the other one of the similar optical signals 1310 and 1312 is still available for routing through destination node 1340 to the attached client equipment 1345. Referring also to Figure 13, even if one of the primary or redundant optical paths 1332 and 1334 of the optical network 1316 fails, caused by, for example, a fiber optic cable being cut or an intermediate node failing, the other one of the similar optical signals 1310 or 1312 will still be transmitted to the destination node 1340 and to the attached client equipment 1345. Accordingly, the same information from the original input optical signal 1304 received at the source node 1302 is still provided to the destination node 1340 and 1+1 optical fault protection is provided for the optical network.

Moreover, because the received similar optical signals 1310 and 1312 are diversely routed through the first and second optical switch cores 240 and 260 of the optical cross-connect switching system 1632 along the first and second optical paths 1642 and 1644, respectively, if one of the first or second paths fails (e.g. due to one of the optical switch cores failing), the other similar optical signal traveling the other path is still available to the destination I/O port card 1650 and the client equipment 1345. Thus, 1+1 optical fault protection is thereby provided within the destination node 1340 itself.

Referring now to Figure 17, a block diagram of another type of redundant architecture for an optical cross-connect switching system is shown according to one embodiment of the present invention. In one embodiment, the optical cross-connect switching system 1702 is used in a source node 1704. Generally, the input optical signal 1304 is first routed through a source I/O port module/card 215_s having a splitter 1705 which splits the input optical signal 1304 into two similar optical signals 1310 and

1312. The two similar optical signals contain the same information. It should be appreciated that the source I/O port card 215_s is a smart port card and has been previously described with reference to Figures 8 and 9. Particularly, the splitter 1705 corresponds to the splitter 620 (previously described) which effectively performs a bridging operation by splitting the input optical signal 1304 into the two similar optical signals 1310 and 1312 that collectively have the same power level (energy) as the original input optical signal 1304. In one embodiment, when the splitter 1705 is a 50/50 splitter, the bridged light signals 1310 and 1312 have equal power levels. However, it is contemplated that splitter 1705 may produce bridged light signals 1310 and 1312 having disproportionate power levels.

Moreover, the input optical signal 1304 is split into two similar optical signals 1310 and 1312 that follow a primary optical path 1710 and a redundant optical path 1712, respectively, through the source node 1704. The two similar optical signals 1310 and 1312 are switched by a source optical switching device 1713 that includes a first optical switch core 240 and a second optical switch core 260. The first of the two similar optical signals, which follows the primary optical path 1710, is switched by the first optical switch core 240 to a first destination I/O port module/card 1716. The selector switch 1720 of the first destination I/O port card 1716 selects the primary optical path 710 and the first similar optical signal 1310 is transmitted to an adjacent intermediate node along a primary optical path of the overall optical network (e.g. along a working fiber) (Fig. 13). Similarly, the second of the two similar optical signals, which follows the redundant optical path 1712, is switched by the second optical switch core 260 to a second destination I/O port module/card 1718. The selector switch 1722 of the second destination I/O port card 1718 selects the redundant optical path 1712 and the second similar optical signal 1312 is transmitted to an adjacent intermediate node along a redundant optical path (e.g. along a protected fiber) such that the two similar optical signals are diversely routed through the optical network (Fig. 13).

It should be noted that first and second destination I/O port cards 1716 and 1718 can be similar to the destination I/O port module/card 215_d previously described with reference to Figures 8 and 9. Furthermore, the first and second destination I/O port cards 1716 and 1718 act as smart cards, each having a selector switch 1720 and 1722, respectively. The selector switches 1720 and 1722 are analogous to the optical switch 610 of destination I/O port card 215_d, previously described. Also, it should be noted that the first and second optical switch cores 240 and 260 both include a plurality of optical switches to accomplish switching as has been previously described. Particularly, the first and second optical switch cores 240 and 260 both include a first optical switch matrix having a plurality of mirrors and a second optical switch matrix having a plurality of mirrors (not shown).

As previously discussed, generally, the two similar optical signals 1310 and 1312 are diversely routed through the source node 1704 along primary and redundant optical paths 1710 and 1712, respectively. However, in this embodiment, if either of the primary or redundant optical paths 1710 or 1712 fails, the first optical switch core 240 redirects the primary optical path 1710 along a redirected primary optical path 1730 (dashed lines) to the second destination I/O port card 1718 and the selector switch 1722 simultaneously selects the redirected primary optical path 1730 and the second optical switch core 260 redirects the redundant optical path 1712 along a redirected redundant optical path 1732 (dashed lines) to the first destination I/O port card 1716 and the selector switch 1720 simultaneously selects the redirected redundant optical path 1732. In one embodiment, the redirection occurs for both the primary optical path 1710 and the redundant optical path 1712, by the mirror of the first optical switch matrix of both the first and second optical switch cores 240 and 260 (associated with the original primary and redundant optical path, respectively) remaining the same and changing the output mirror of the second optical switch matrix of both the first and second optical switch cores such that both the primary and redundant optical paths are redirected to assume the redirected primary and redundant optical paths 1730 and 1732

to the associated destination I/O port card, respectively. Accordingly, both of the two similar optical signals 1310 and 1312 are still routed through the source node despite the failure of one, or both, of the primary or redundant optical paths.

In this way, fault protection is enabled within the optical cross-connect switching system 1702. Advantageously, not only does this embodiment provide 1+1 fault protection within optical cross-connect switching system 1702, but this embodiment can also protect against multiple failures (e.g. multiple mirrors becoming disabled). Also, it should be appreciated that the optical cross-connect switching system 1702, previously described, can also be utilized with intermediate and destination nodes.

It should also be appreciated that the previously described source nodes, intermediate nodes, and destination nodes and the optical cross-connect switching systems used therein can be used as an optical bridge, an optical router, an optical hub, an optical node, an optical concentrator, or other types of networking equipment accepting an optical signal.

Thus, the embodiments of the present invention provide methods, systems, and data communication networks for providing fault protection in an optical network. Particularly, source nodes, intermediate nodes, and destination nodes having particular optical cross-connect switching system architectures have been disclosed that can be used to provide 1+1 optical fault protection within an optical network. Moreover, the architectures of the source nodes, intermediate nodes, and destination nodes have fault protection mechanisms built within the nodes themselves. Accordingly, the present invention provides an optical, scalable cross-connect system with a variety features such as redundancy for fault protection and rapid restoration that can be used to implement 1+1 optical fault protection within an optical network as well as within the individual nodes themselves. Furthermore, the present invention provides an all optical, scalable cross-connect system which performs switching operations of light

signals without converting and reconverting signals between the optical domain to the electrical domain.

While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art.

CLAIMS

What is claimed is:

1. A data communication network to provide fault protection, the data communication network comprising:

a source optical cross-connect switching system including,

a splitter to split an input optical signal into two similar optical signals; and

a source optical switching device to switch the two similar optical signals to adjacent cross-connects such that the two similar optical signals are diversely routed through an optical network to a common destination optical cross-connect switching system.

2. The data communication network of claim 1 wherein, the destination optical cross-connect switching system to receive the two similar optical signals, includes,

a destination optical switching device to switch each of the two similar optical signals to a selector switch to select one of the two similar optical signals, wherein, if one of the diversely routed similar optical signals fails to reach the destination optical cross-connect switching system due to a fault in the optical network, the other one of the similar optical signals is still available to the destination optical cross-connect switching system.

3. The data communication network of claim 1 wherein,

the source optical switching device includes an optical switch core having a plurality of optical switches to switch one of the two similar optical signals to a first destination port card and the other one of the similar optical signals to a second destination port card, respectively.

4. The data communication network of claim 1 wherein,

the source optical switching device includes a first optical switch core including a plurality of optical switches and a second optical switch core including a plurality of optical switches, the first optical switch core to switch one of the two similar optical signal to one of a first or a second destination port card and the second optical switch core to switch the other one of the similar optical signals to a different one of the first or the second destination port cards.

5. The data communication network of claim 4 wherein,

the first and second destination port cards of the source optical cross-connect switching system are passive port cards.

6. The data communication network of claim 4 wherein,

the first and second destination port cards of the source optical cross-connect switching system are smart port cards having a selector switch set to a predefined position to select one of the similar optical signals.

7. The data communication network of claim 4 wherein,

the first and second destination port cards of the source optical cross-connect switching system are each coupled to different adjacent cross-connects.

8. The data communication network of claim 1 wherein,

the source optical cross-connect switching system includes a source smart port card which includes the splitter, the source smart port card to receive the input optical signal.

9. The data communication network of claim 7 wherein,

the source smart port card to receive the input optical signal is connected to client equipment.

10. The data communication network of claim 2 wherein,

the destination optical switching device includes an optical switch core of optical switches to switch each of the similar optical signals to a destination port card.

11. The data communication network of claim 2 wherein,

the destination optical switching device includes a first optical switch core including a plurality of optical switches and a second optical switch core including a plurality of optical switches, the first optical switch core to switch one of the similar optical signals to a destination port card and the second optical switch core to also switch the other of the similar optical signals to the destination port card.

12. The data communication network of claim 2 wherein,

the destination optical cross-connect switching system includes first and second passive source port cards to receive the two similar optical signals.

13. The data communication network of claim 2 wherein,

the destination optical cross-connect switching system includes first and second smart source port cards having a selector switch set to a predefined position to select one of the similar optical signals.

14. The data communication network of claim 11 wherein,

the destination port card of the destination optical cross-connect switching

system is a smart port card having a selector switch to select one of the similar optical signals.

15. The data communication network of claim 11 wherein,

the destination port card of the destination optical cross-connect switching system is connected to client equipment.

16. The data communication network of claim 1 further comprising,

at least one intermediate optical cross-connect switching system located between the source optical cross-connect switching system and the destination optical cross-connect switching system.

17. The data communication network of claim 16 wherein,

the at least one intermediate optical cross-connect switching system includes a passive source port card to receive one of the two similar optical signals and an intermediate optical switching device to switch the one of the received similar optical signals to a destination port card such that the one of the received similar optical signals continues being routed through the optical network.

18. The data communication network of claim 17 wherein,

the intermediate optical switching device includes an optical switch core having a plurality of optical switches to switch one of the received similar optical signals to the destination port card of the intermediate optical cross-connect switching system.

19. The data communication network of claim 16 wherein,

the at least one intermediate optical cross-connect switching system includes a source smart port card with a splitter to split one of the two similar optical signals into

two split optical signals, respectively, and an intermediate optical switching device to switch each of two split optical signals to a destination smart port card having a selector switch to select one of the two split optical signals, wherein, if one of the diversely routed split optical signals fails within the intermediate optical cross-connect switching system the other one of the two split optical signals corresponding to one of the two similar optical signals can still be used for routing through the optical network.

20. The data communication network of claim 19 wherein,

the intermediate optical switching device includes a first optical switch core including a plurality of optical switches and second optical switch core including a plurality of optical switches, the first optical switch core to switch one of the two split optical signals to the destination smart port card of the intermediate optical cross-connect switching system and the second optical switch core to similarly switch the other one of the split optical signals to the destination smart port card of the intermediate optical cross-connect switching system.

21. The data communication network of claim 1 wherein,

the source optical cross-connect switching system includes first and second smart destination port cards each having a selector switch to select one of the two similar optical signals.

22. The data communication network of claim 21 wherein,

the source optical switching device includes a first optical switch core including a plurality of optical switches and a second optical switch core including a plurality of optical switches, the first optical switch core to switch one of the two similar optical signals to the first destination smart port card of the source optical cross-connect switching system and the second optical switch core to switch the other of the two similar optical signals to the second destination smart port card of the source optical

cross-connect switching system, wherein if a failure occurs in switching one of the two similar optical signals, the first optical switch core redirects one of the two similar optical signals to the second destination smart port card and the second optical switch core redirects the other of the two similar optical signals to the first destination smart port card, the first and second destination smart port cards selecting the redirected similar optical signal, respectively, thereby enabling fault protection within the source optical cross-connect switching system.

23. The data communication network of claim 1 wherein,

the source optical cross-connect switching system and the destination optical cross-connect switching system are one of an optical bridge, an optical router, an optical hub, an optical node, an optical concentrator, or other networking equipment accepting an optical signal.

24. A system to provide fault protection in an optical network, the system comprising:

a source node including an optical cross-connect switching system having a source port card with a splitter to split an input optical signal into two similar optical signals and a source optical switching device to switch one of the two similar optical signals to a first destination port card and the other one of the similar optical signals to a second destination port card, respectively, such that the two similar optical signals are diversely routed through the optical network to a same destination node.

25. The system of claim 24 wherein,

the destination node includes an optical cross-connect switching system to receive the two similar optical signals via first and second source port cards, respectively, the optical cross-connect switching system including a destination optical switching device to switch each of the two similar optical signals to a destination port

card having a selector switch to select one of the two similar optical signals, wherein, if one of the diversely routed similar optical signals fails to reach the destination node due to a fault in the optical network the other one of the similar optical signals is still available to the destination port card of the destination node.

26. The system of claim 24 wherein,

the source optical switching device includes an optical switch core having a plurality of optical switches to switch one of the two similar optical signals to the first destination port card and other one of the similar optical signals to the second destination port card, respectively.

27. The system of claim 24 wherein,

the source optical switching device includes a first optical switch core including a plurality of optical switches and a second optical switch core including a plurality of optical switches, the first optical switch core to switch one of the two similar optical signals to one of the first and second destination port cards of the source node and the second optical switch core to switch the other of the similar optical signals to a different one of the first and second destination port cards of the source node.

28. The system of claim of claim 24 wherein,

the source port card of the source node is a smart port card.

29. The system of claim 24 wherein,

the source port card of the source node to receive the input optical signal is connected to client equipment.

30. The system of claim 24 wherein,

the first and second destination port cards of the source node are passive port cards.

31. The system of claim 24 wherein,

the first and second destination port cards of the source node are smart port cards having a selector switch set to a predefined position to select one of the similar optical signals.

32. The system of claim 24 wherein,

the first and second destination port cards of the source node are each connected to different intermediate nodes.

33. The system of claim 25 wherein,

the destination optical switching device includes an optical switch core of optical switches to switch each of the similar optical signals to the destination port card..

34. The system of claim 25 wherein,

the destination optical switching device includes a first optical switch core including a plurality of optical switches and a second optical switch core including a plurality of optical switches, the first optical switch core to switch one of the similar optical signals to the destination port card and the second optical switch core to switch the other of the similar optical signals to the destination port card.

35. The system of claim of claim 25 wherein,

the first and second source port cards of the destination node are passive port cards.

36. The system of claim 25 wherein,

the first and second source port cards of the destination node are smart port cards having a selector switch set to a predefined position to select one of the similar optical signals.

37. The system of claim 25 wherein,

the destination port card of the destination node is a smart port card having a selector switch to select one of the similar optical signals.

38. The system of claim 25 wherein,

the destination port card of the destination node is connected to client equipment.

39. The system of claim 24 further comprising,

at least one intermediate node located between the source node and the destination node.

40. The system of claim 39 wherein,

the at least one intermediate node includes an optical cross-connect switching system having a passive source port card to receive one of the two similar optical signals and an intermediate optical switching device to switch the one of the received similar optical signals to a destination port card such that the one of the received similar optical signals continues being routed through the optical network.

41. The system of claim 40 wherein,

the intermediate optical switching device includes an optical switch core having

a plurality of optical switches to switch one of the received similar optical signals to the destination port card of the intermediate node.

42. The system of claim 39 wherein,

the at least one intermediate node includes an optical cross-connect switching system having a source smart port card with a splitter to split one of the two similar optical signals into two split optical signals, respectively, and an intermediate optical switching device to switch each of two split optical signals to a destination smart port card having a selector switch to select one of the two split optical signals, wherein, if one of the diversely routed split optical signals fails within the optical cross-connect switching system of the intermediate node the other one of the two split optical signals corresponding to one of the two similar optical signals can still be used for routing through the optical network.

43. The system of claim 42 wherein,

the intermediate optical switching device includes a first optical switch core including a plurality of optical switches and a second optical switch core including a plurality of optical switches, the first optical switch core to switch one of the two split optical signals to the destination smart port card of the intermediate node and the second optical switch core to switch the other one of the split optical signals to the destination smart port card of the intermediate node.

44. The system of claim 24 wherein,

the first and second destination port cards of the source node are smart port cards each having a selector switch to select one of the two similar optical signals.

45. The system of claim 44 wherein,

the source optical switching device includes a first optical switch core including

a plurality of optical switches and a second optical switch core including a plurality of optical switches, the first optical switch core to switch one of the two similar optical signals to the first destination smart port card of the source node and the second optical switch core to switch the other of the two similar optical signals to the second destination smart port card of the source node, wherein if a failure occurs in switching one of the two similar optical signals, the first optical switch core redirects one of the two similar optical signals to the second destination smart port card and the second optical switch core redirects the other of the two similar optical signals to the first destination smart port card, the first and second destination smart port cards selecting the redirected similar optical signal, respectively, thereby enabling fault protection within the optical cross-connect switching system of the source node.

46. The system of claim 24 wherein,

the source node and the destination node are one of an optical bridge, an optical router, an optical cross-connect switch, an optical hub, an optical concentrator, or other networking equipment accepting an optical signal.

47. A method to provide fault protection in an optical network, the method comprising:

splitting an input optical signal into two similar optical signals; and

switching each of the similar optical signals at a source node of the optical network to adjacent nodes of the optical network such that the two similar optical signals are diversely routed through the optical network to a common destination node.

48. The method of claim 47 further comprising,

receiving the two similar optical signals at the destination node of the optical network; and

selecting one of the two similar optical signals at the destination node, wherein, if one of the diversely routed similar optical signals fails to reach the destination node due to a fault in the optical network the other one of the similar optical signals is still available.

49. The method of claim 47 wherein,

switching each of the similar optical signals at the source node includes utilizing an optical switch core having a plurality of optical switches to switch each of the similar optical signals, respectively.

50. The method of claim 47 wherein,

switching each of the similar optical signals at the source node includes utilizing a first optical switch core having a plurality of optical switches and a second optical switch core having a plurality of optical switches, the first optical switch core to switch one of the two similar optical signal to one of the adjacent nodes of the optical network and the second optical switch core to switch the other of the similar optical signals to a different adjacent node of the optical network.

51. The method of claim 47 wherein,

receiving an input optical signal includes using a smart port card at the source node to receive the input signal.

52. The method of claim 47 wherein,

the source node is connected to client equipment.

53. The method of claim 47 wherein,

switching each of the similar optical signals at the source node of the optical

network to adjacent nodes of the optical network includes routing the similar optical signals through first and second destination passive port cards of the source node.

54. The method of claim 48 wherein, selecting one of the two similar optical signals at the destination node comprises:

switching the two similar optical signals with an optical switch core having a plurality of optical switches to a destination smart port card having a selector switch to select one of the similar optical signals.

55. The method of claim 48 wherein, selecting one of the two similar optical signals at the destination node comprises:

switching the two similar optical signals with a first optical switch core including a plurality of optical switches and a second optical switch core including a plurality of optical switches, the first optical switch core to switch one of the two similar optical signals to a destination smart port card of the destination node and the second optical switch core to switch the other of the similar optical signals to the destination smart port card, the destination smart port card having a selector switch to select one of the similar optical signals.

56. The method of claim 55 wherein,

the destination smart port card of the destination node is connected to client equipment.

57. The method of claim 47 wherein,

at least one intermediate node is located between the source node and the destination node.

58. The method of claim 57 further comprising,

receiving one of the similar optical signals at one of the intermediate nodes; and

switching the one of the received similar optical signals to a destination port card of the intermediate node such that the one of the received similar optical signals continues being routed through the optical network.

59. The method of claim 58 wherein,

switching the one of the received similar optical signals at the intermediate node includes utilizing an optical switch core having a plurality of optical switches to switch the one of the received similar optical signals to the destination port card.

60. The method of claim 58 wherein, switching the one of the received similar optical signals at the intermediate node comprises:

splitting the one of the received similar optical signals into two split optical signals;

switching each of two split optical signals to the destination port card of the intermediate node utilizing a first optical switch core including a plurality of optical switches and a second optical switch core including a plurality of optical switches, the first optical switch core to switch one of the two split optical signals to the destination port card and the second optical switch core to switch the other one of the two split optical signals to the destination port card; and

selecting one of the two split optical signals, wherein, if one of the diversely routed two split optical signals fails within the intermediate node the other one of the two split optical signals corresponding to the one of the two similar optical signals can still be used for routing through the optical network.

61. The method of claim 47 wherein, switching each of the similar optical signals at the source node of the optical network to adjacent nodes of the optical

network comprises:

switching each of the similar optical signals at the source node utilizing a first optical switch core having a plurality of optical switches and a second optical switch core having a plurality of optical switches, the first optical switch core to switch one of the two similar optical signals to a first destination port card coupled to one of the adjacent nodes of the optical network and the second optical switch core to switch the other of the similar optical signals to a second destination port card coupled to a different adjacent node of the optical network; and

if a failure occurs in switching one of the two similar optical signals,

redirecting one of the two similar optical signals with the first optical switch core to the second destination smart port card;

redirecting the other of the two similar optical signals with the second optical switch core to the first destination smart port card; and

selecting the redirected one of the two similar optical signals and the redirected other of the two similar optical signals at the first and second destination port cards, respectively, thereby enabling fault protection within the optical cross-connect switching system of the source node.

62. The method of claim 47 wherein,

the source node and the destination node are one of an optical bridge, an optical router, an optical cross-connect switch, an optical hub, an optical concentrator, or other networking equipment accepting an optical signal.

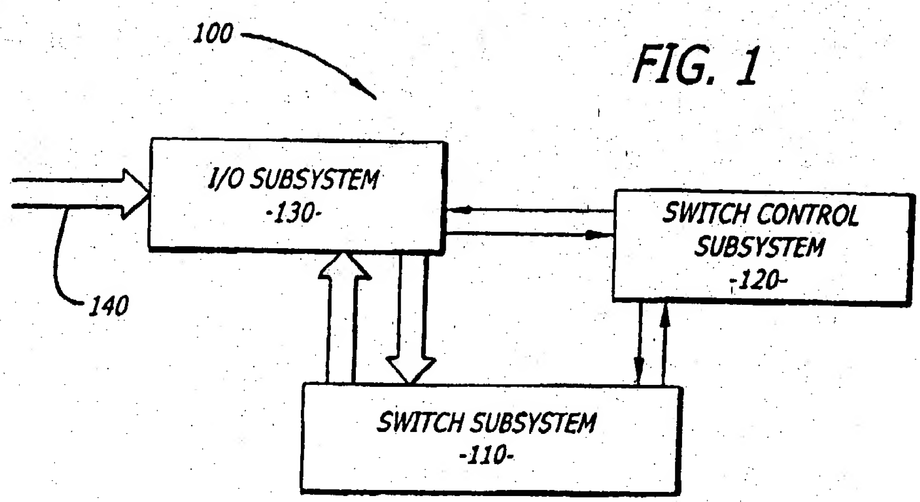

100
I/O SUBSYSTEM
-130-
SWITCH CONTROL
SUBSYSTEM
-120-
140
SWITCH SUBSYSTEM
-110-

FIG. 1

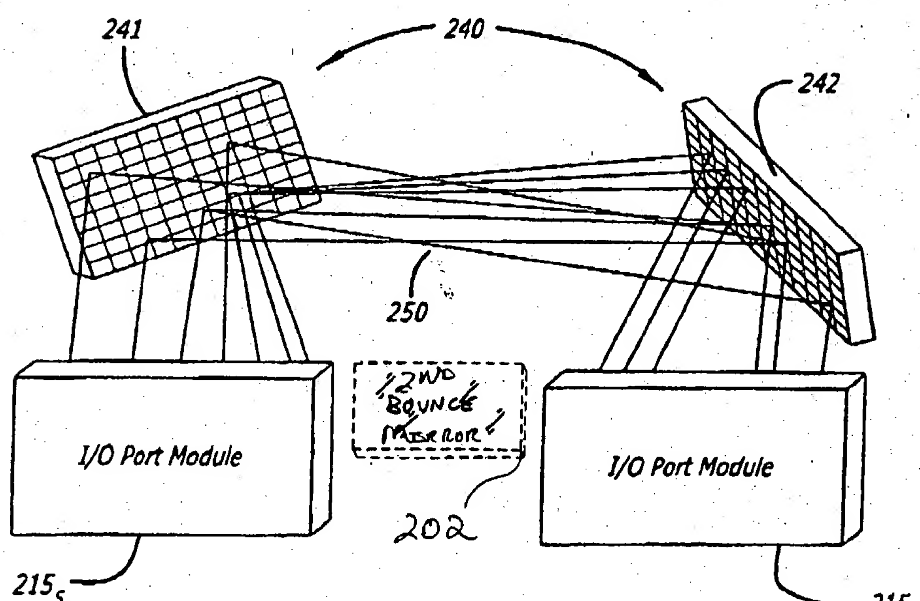

241
240
242
250
2ND
BOUNCE
MIRROR
I/O Port Module
I/O Port Module
202
215_s
215_d

FIG. 3

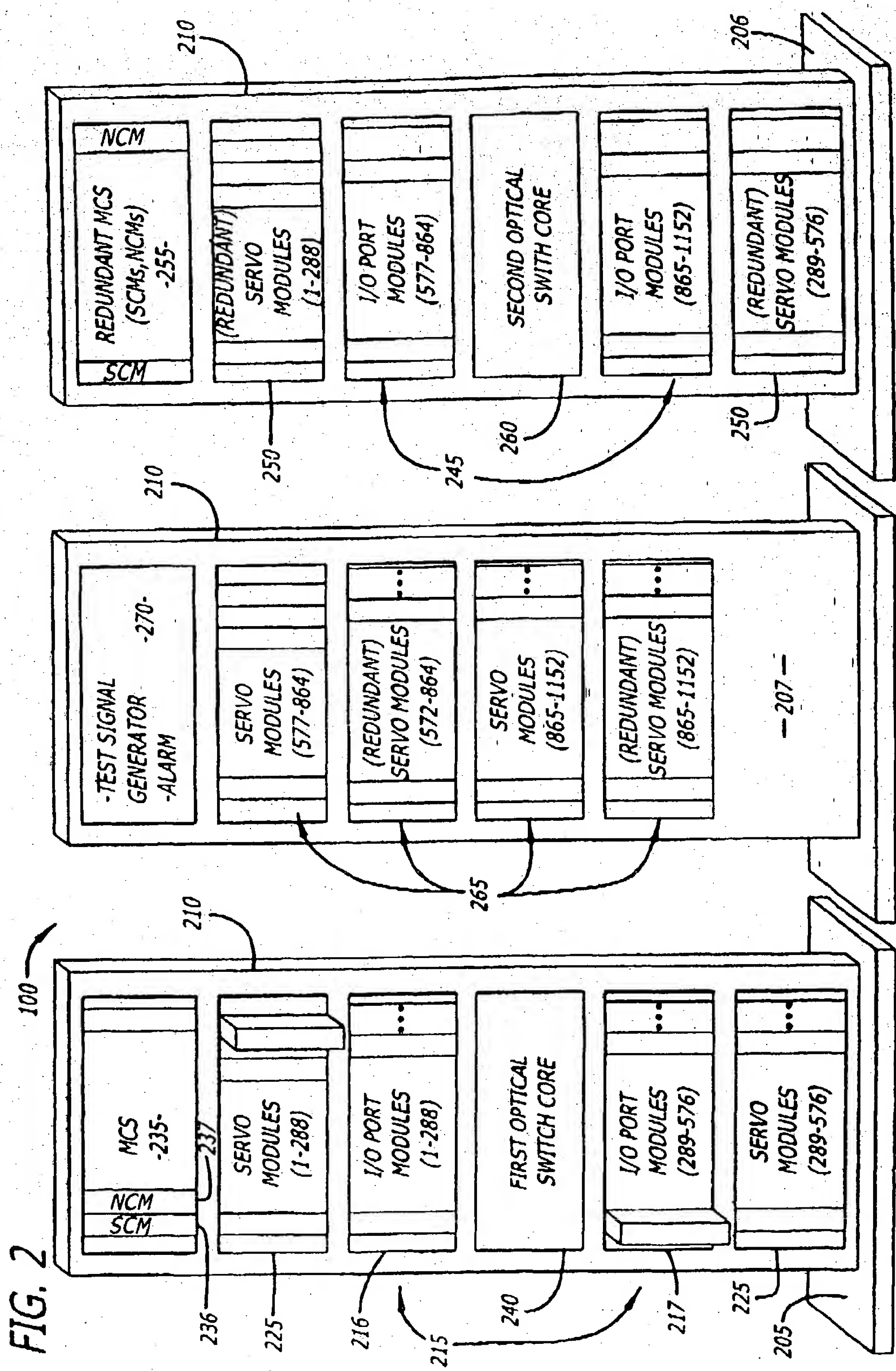

NCM
REDUNDANT MCS (SCMs,NCMs) -255-
SCM
(REDUNDANT) SERVO MODULES (1-288)
I/O PORT MODULES (577-864)
SECOND OPTICAL SWITH CORE
I/O PORT MODULES (865-1152)
(REDUNDANT) SERVO MODULES (289-576)
210
206
250
260
245
-TEST SIGNAL GENERATOR -ALARM -270-
SERVO MODULES (577-864)
(REDUNDANT) SERVO MODULES (572-864)
SERVO MODULES (865-1152)
(REDUNDANT) SERVO MODULES (865-1152)
207
265
100
MCS -235-
NCM
SCM
237
SERVO MODULES (1-288)
I/O PORT MODULES (1-288)
FIRST OPTICAL SWITCH CORE
I/O PORT MODULES (289-576)
SERVO MODULES (289-576)
236
225
216
215
240
217
205

FIG. 2

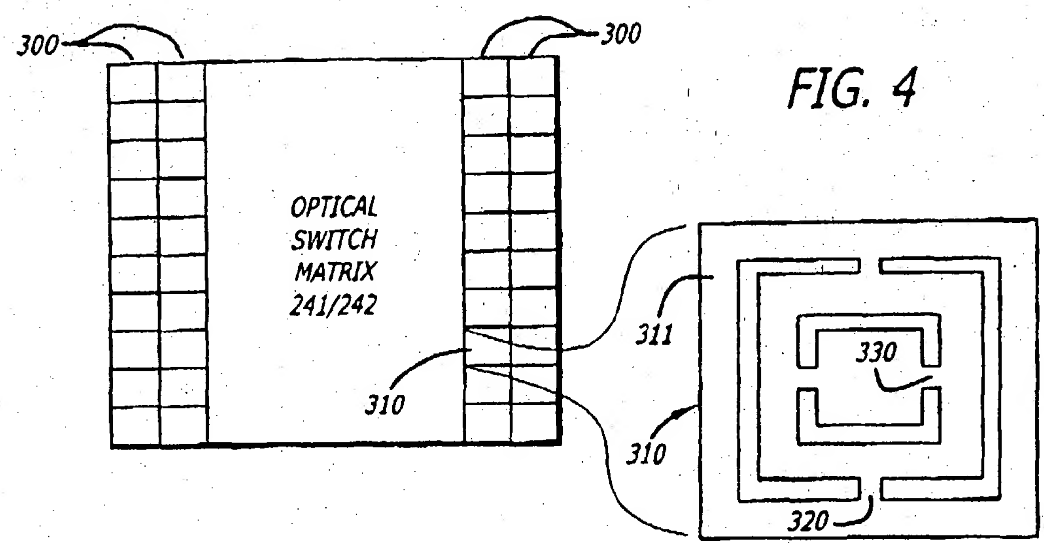

300
300
OPTICAL
SWITCH
MATRIX
241/242
310
311
330
310
320

FIG. 4

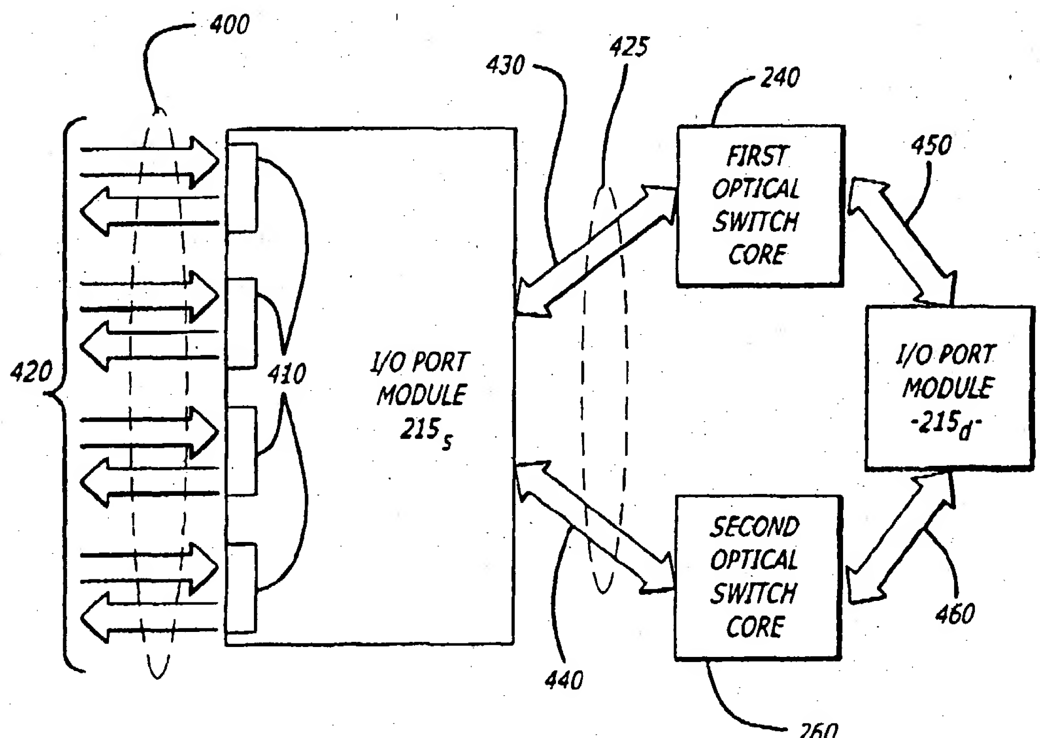

400
430
425
240
FIRST
OPTICAL
SWITCH
CORE
450
420
410
I/O PORT
MODULE
215s
I/O PORT
MODULE
-215d-
SECOND
OPTICAL
SWITCH
CORE
460
440
260

FIG. 6

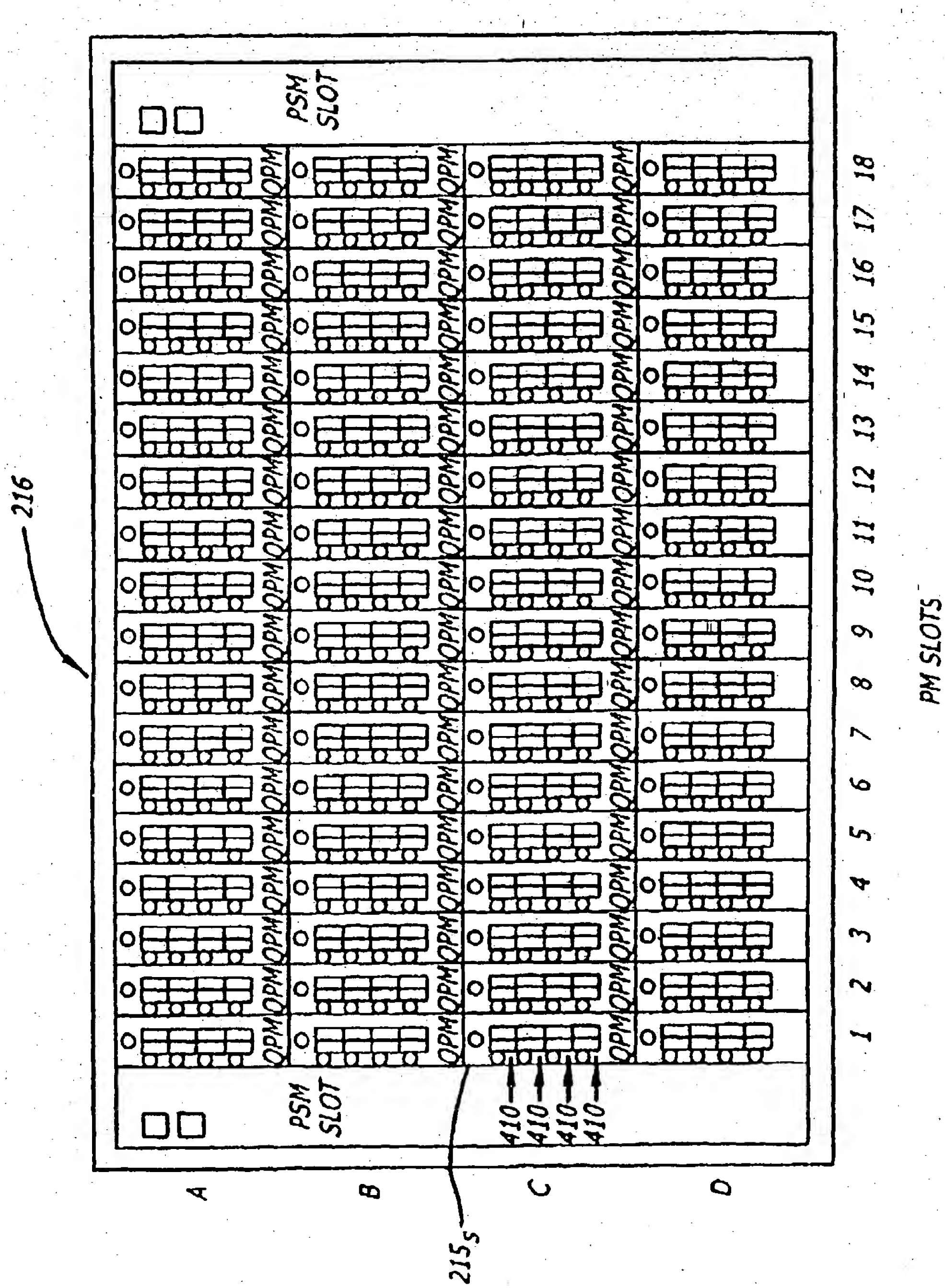

216
PSM SLOT
OPM
PSM SLOT
A
B
C
D
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
PM SLOTS
410
410
410
410
215s

FIG. 5

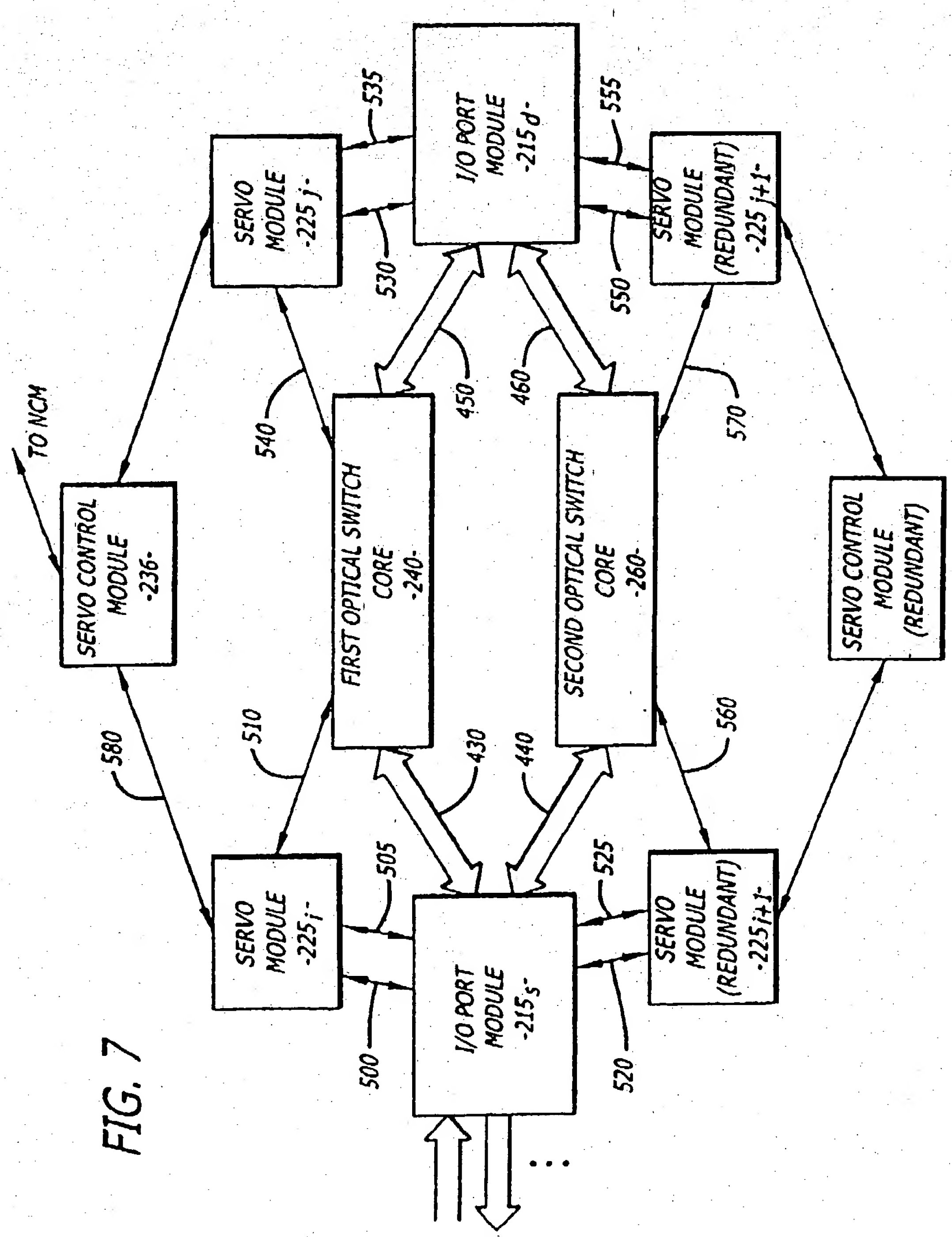

I/O PORT MODULE -215d-
SERVO MODULE -225j-
SERVO MODULE (REDUNDANT) -225j+1-
SERVO CONTROL MODULE -236-
TO NCM
FIRST OPTICAL SWITCH CORE -240-
SECOND OPTICAL SWITCH CORE -260-
SERVO CONTROL MODULE (REDUNDANT)
SERVO MODULE -225i-
I/O PORT MODULE -215s-
SERVO MODULE (REDUNDANT) -225i+1-
535
530
555
550
540
450
460
570
580
510
430
440
560
505
500
525
520

FIG. 7

FIG. 8

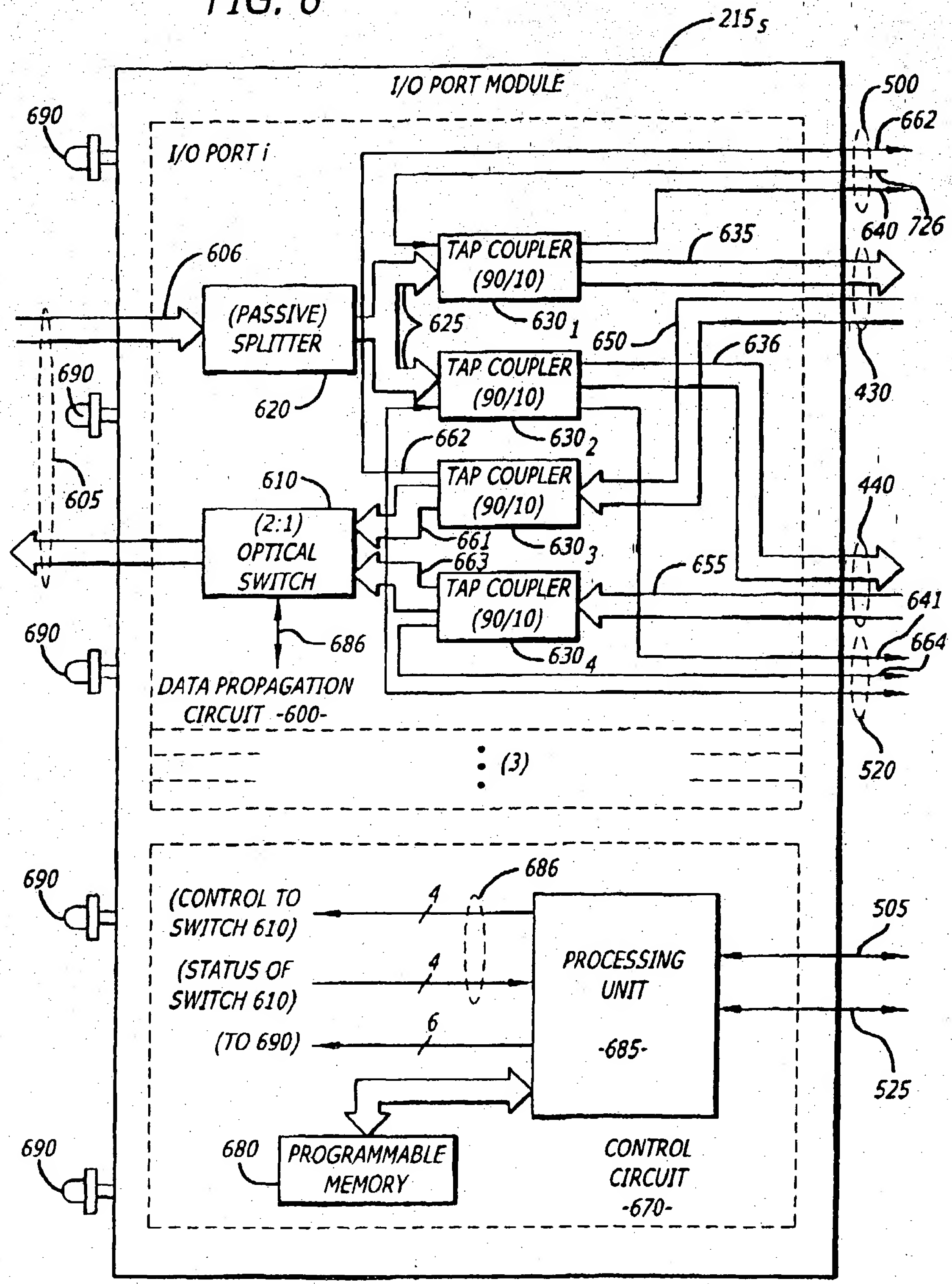
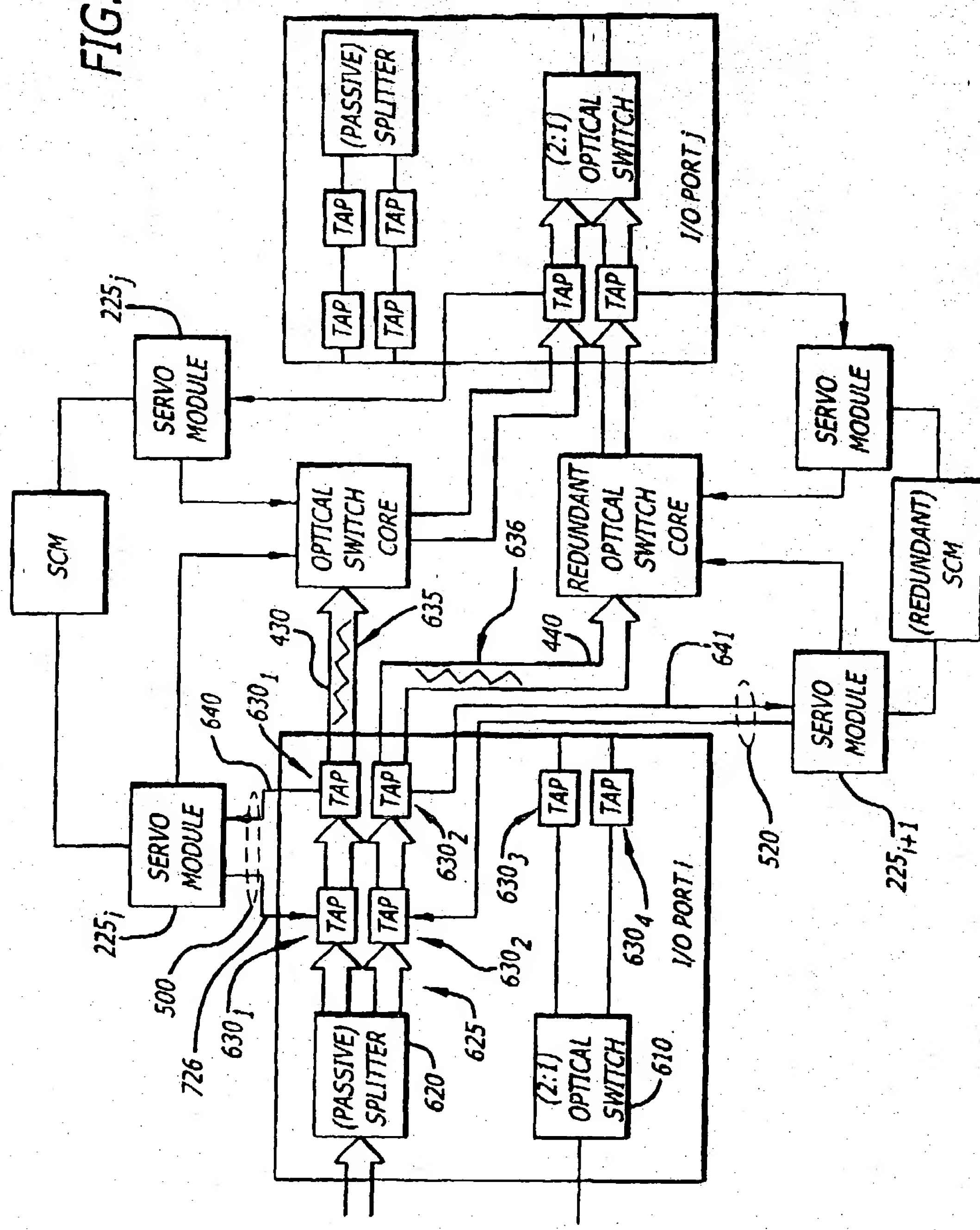

215 s
I/O PORT MODULE
I/O PORT i
690
500
662
640
726
606
(PASSIVE) SPLITTER
620
TAP COUPLER (90/10)
630 1
625
635
650
636
430
TAP COUPLER (90/10)
630 2
662
610
TAP COUPLER (90/10)
630 3
440
661
663
(2:1) OPTICAL SWITCH
655
TAP COUPLER (90/10)
630 4
641
664
605
686
DATA PROPAGATION CIRCUIT -600-
(3)
520
686
(CONTROL TO SWITCH 610)
4
(STATUS OF SWITCH 610)
4
(TO 690)
6
PROCESSING UNIT -685-
505
525
680
PROGRAMMABLE MEMORY
CONTROL CIRCUIT -670-

FIG. 9


SCM
SERVO MODULE
225j
OPTICAL SWITCH CORE
REDUNDANT OPTICAL SWITCH CORE
SERVO MODULE
(REDUNDANT) SCM
SERVO MODULE
(PASSIVE) SPLITTER
TAP
TAP
TAP
TAP
(2:1) OPTICAL SWITCH
TAP
TAP
I/O PORT j
635
636
430
440
641
640
630₁
630₂
630₃
630₄
225i
225i+1
500
520
726
620
625
610
(PASSIVE) SPLITTER
(2:1) OPTICAL SWITCH
I/O PORT i

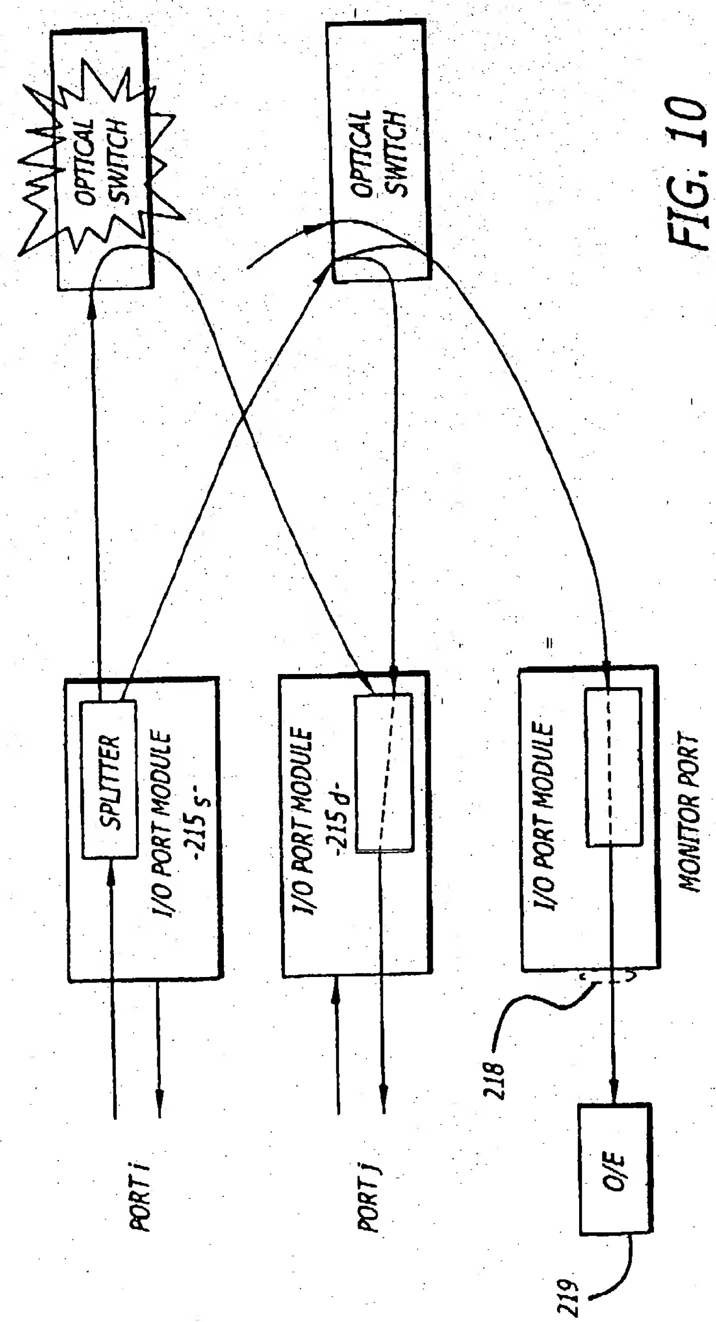

OPTICAL SWITCH
OPTICAL SWITCH
SPLITTER
I/O PORT MODULE
-215 s-
I/O PORT MODULE
-215 d-
I/O PORT MODULE
MONITOR PORT
PORT i
PORT j
218
O/E
219

FIG. 10

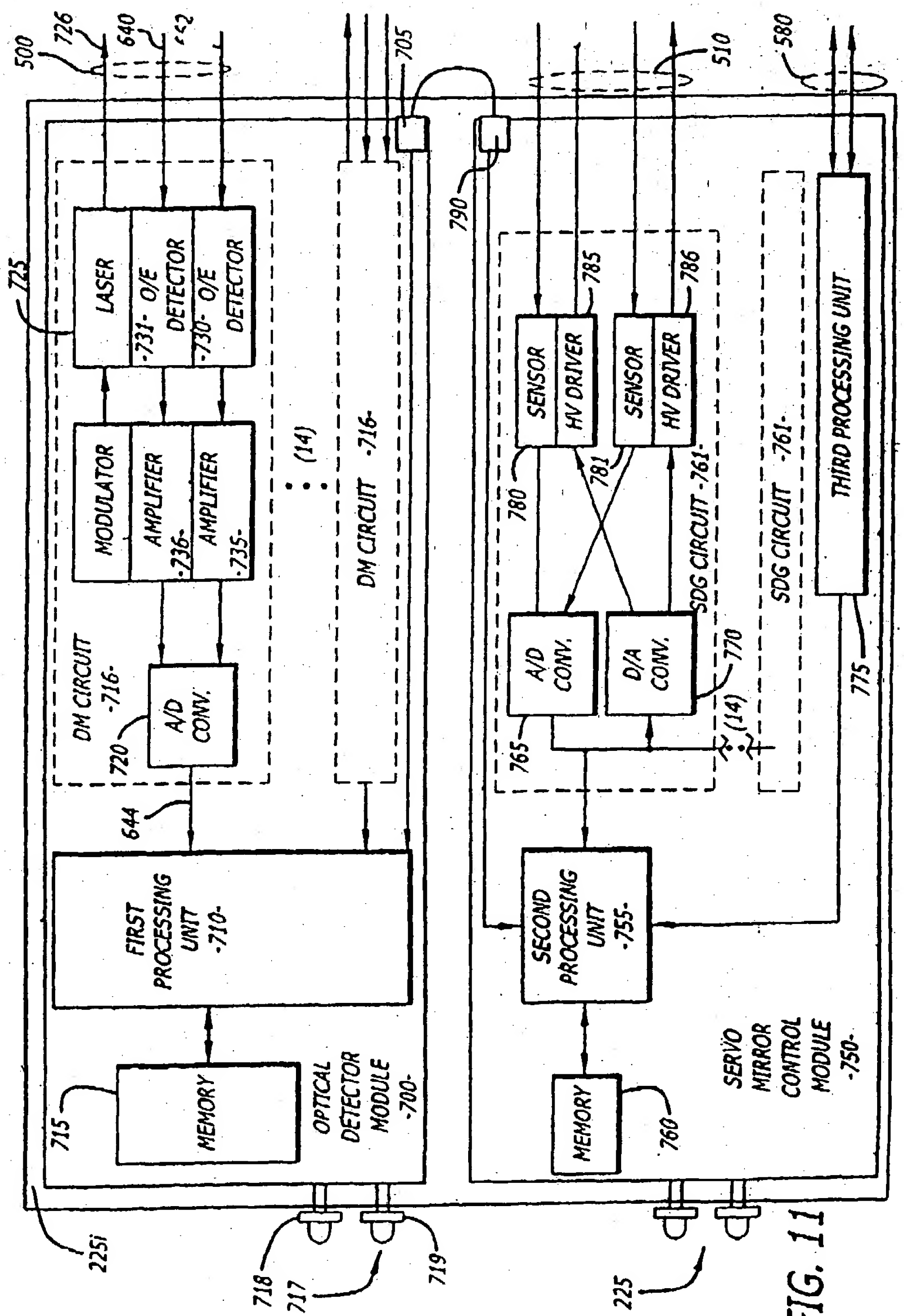

LASER
O/E DETECTOR
O/E DETECTOR
MODULATOR
AMPLIFIER
AMPLIFIER
A/D CONV.
DM CIRCUIT -716-
(14)
FIRST PROCESSING UNIT -710-
MEMORY
OPTICAL DETECTOR MODULE -700-
SENSOR
HV DRIVER
SENSOR
HV DRIVER
A/D CONV.
D/A CONV.
SDG CIRCUIT -761-
THIRD PROCESSING UNIT
SECOND PROCESSING UNIT -755-
MEMORY
SERVO MIRROR CONTROL MODULE -750-
500
726
640
705
510
580
725
731
730
236
735
720
644
715
790
785
786
780
781
765
770
775
760
225i
718
717
719
225

FIG. 11

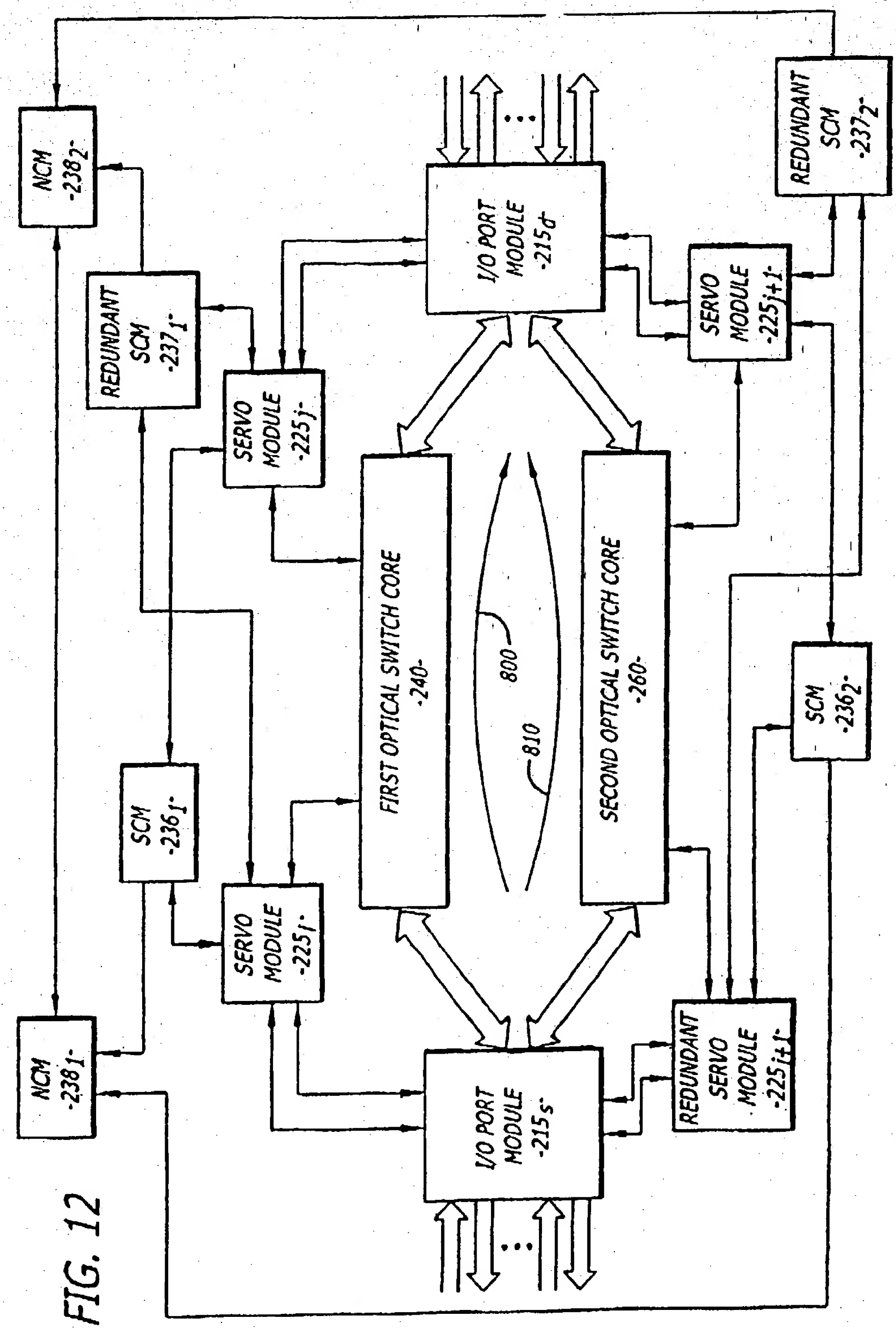

NCM -238$_2$-
REDUNDANT SCM -237$_1$-
SERVO MODULE -225$_j$-
I/O PORT MODULE -215$_d$-
SERVO MODULE -225$_{j+1}$-
REDUNDANT SCM -237$_2$-
FIRST OPTICAL SWITCH CORE -240-
800
810
SECOND OPTICAL SWITCH CORE -260-
SCM -236$_1$-
SCM -236$_2$-
SERVO MODULE -225$_i$-
NCM -238$_1$-
I/O PORT MODULE -215$_s$-
REDUNDANT SERVO MODULE -225$_{i+1}$-

FIG. 12

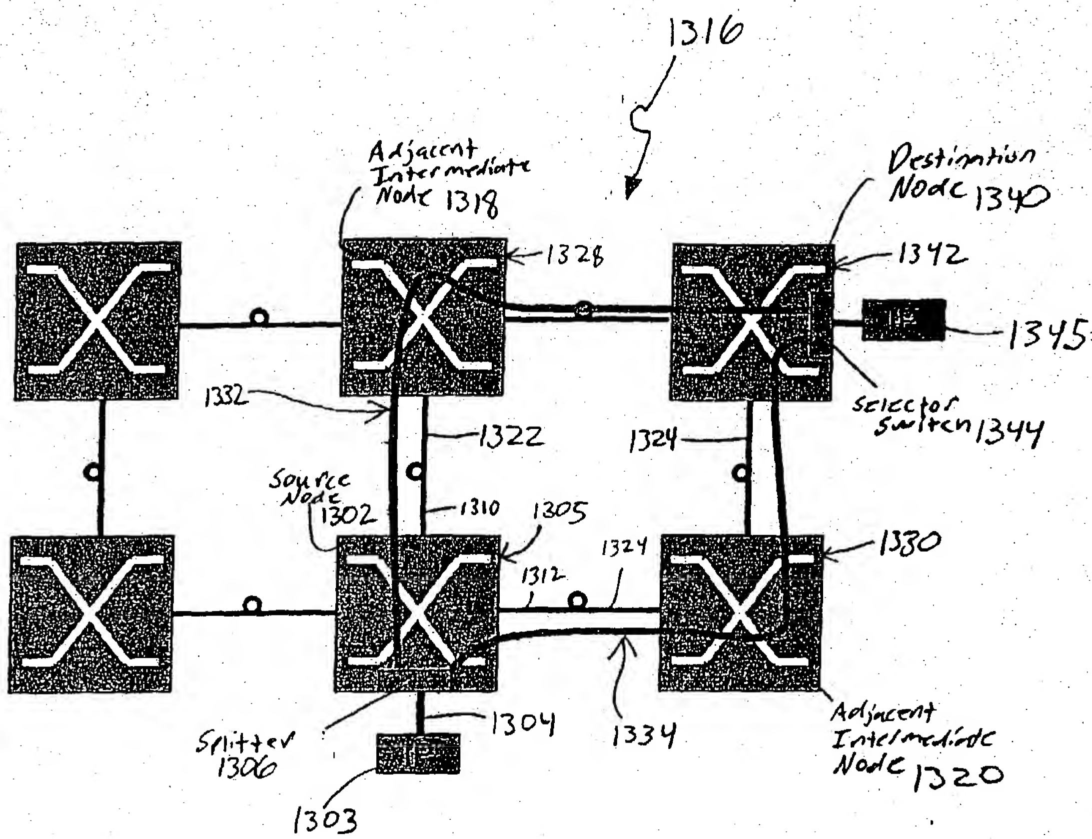

1316
Adjacent Intermediate Node 1318
1328
Destination Node 1340
1342
1345
1332
1322
1324
Selector Switch 1344
Source Node 1302
1310
1305
1324
1312
1330
1304
1334
Adjacent Intermediate Node 1320
Splitter 1306
1303

FIG. 13

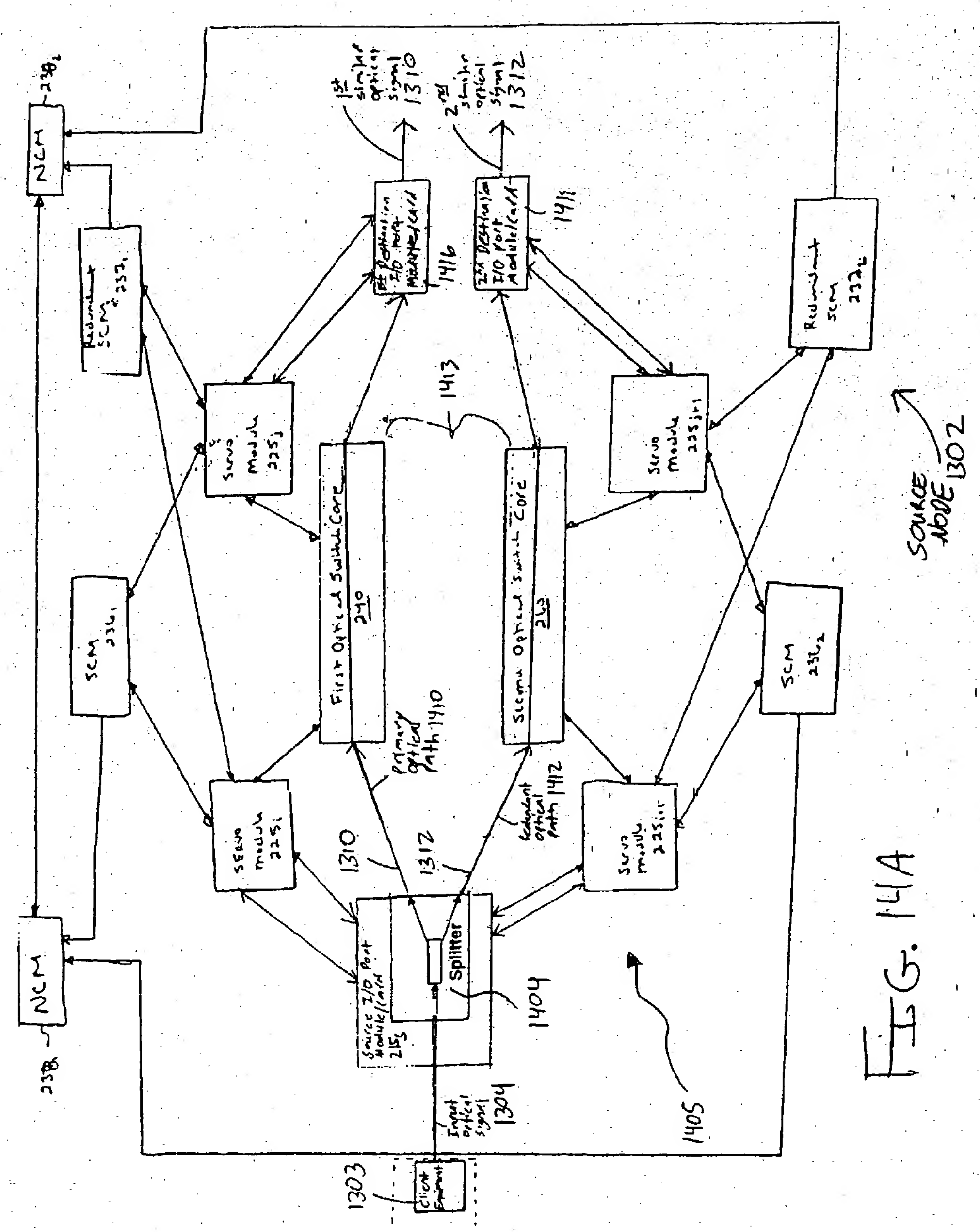

NCM
SCM
Redundant SCM
Servo module
First Optical Switch Core 210
Second Optical Switch Core 213
Splitter
Primary optical path 1410
Redundant optical path 1412
Input optical signal 1304
1st similar optical signal 1310
2nd similar optical signal 1312
SOURCE NODE 1302
1303
1404
1405
1413
1416

FIG. 14A

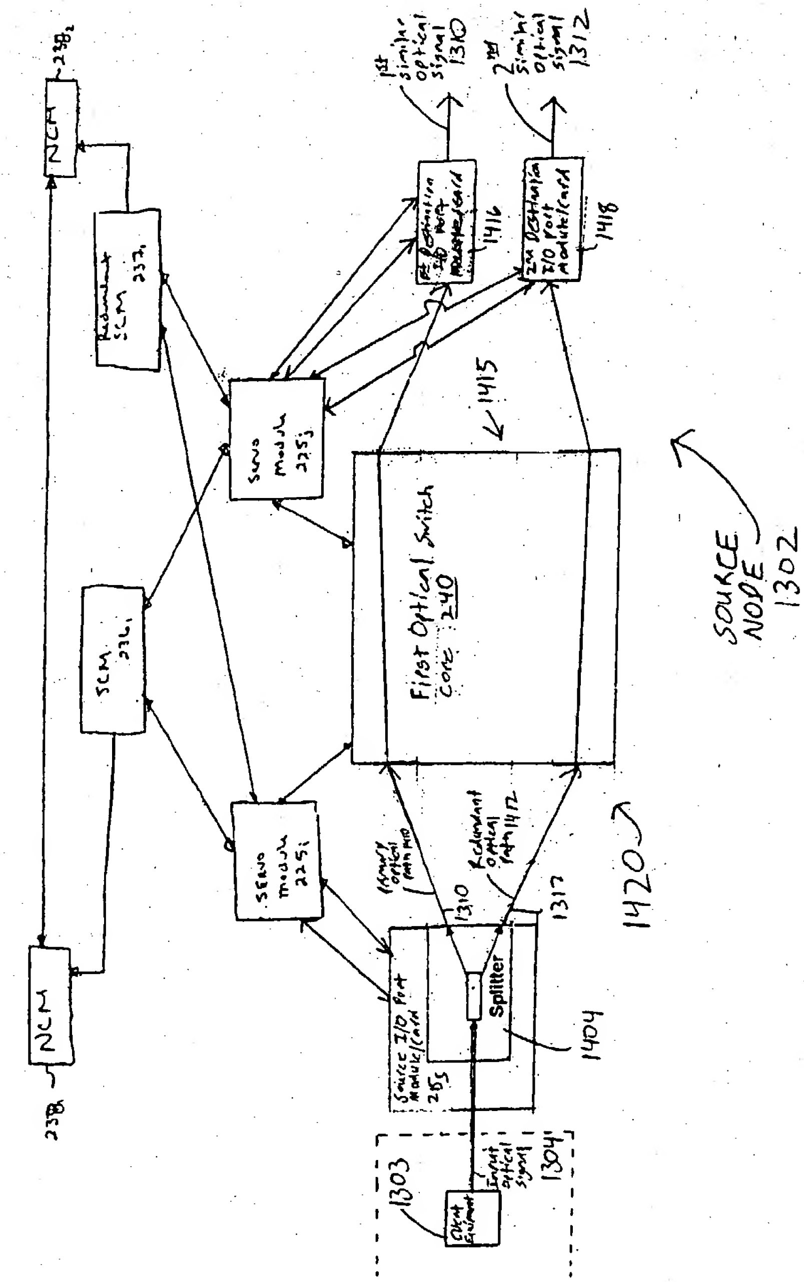

NCM
SCM 232
Servo Module 225j
Servo Module 225i
First Optical Switch Core 240
Splitter
1404
1415
1416
1418
1420
1303
1304
SOURCE NODE 1302

FIG. 14B

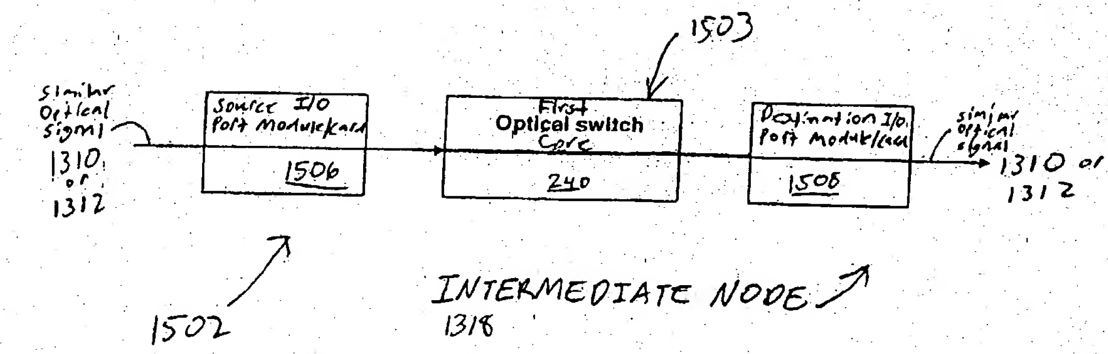


FIG. 15A

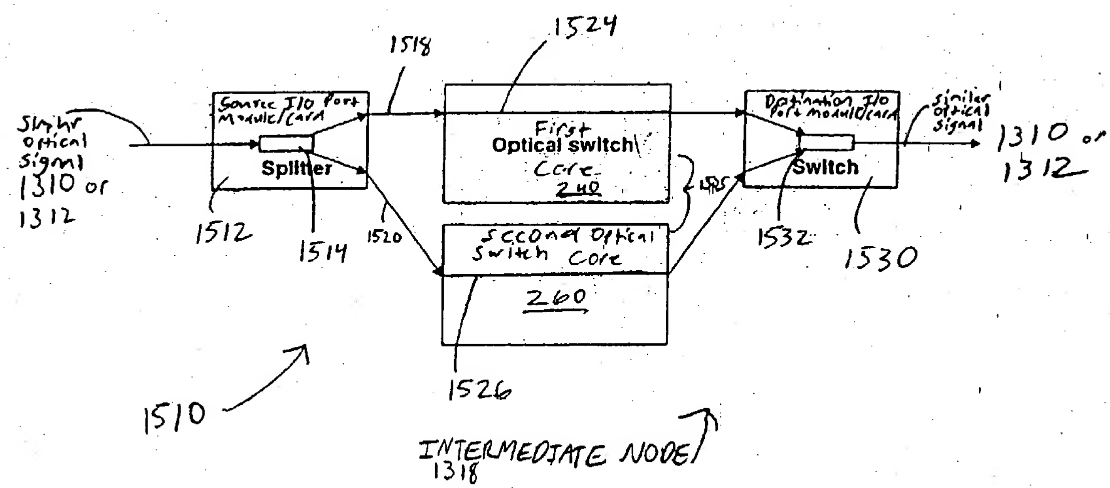


FIG. 15B

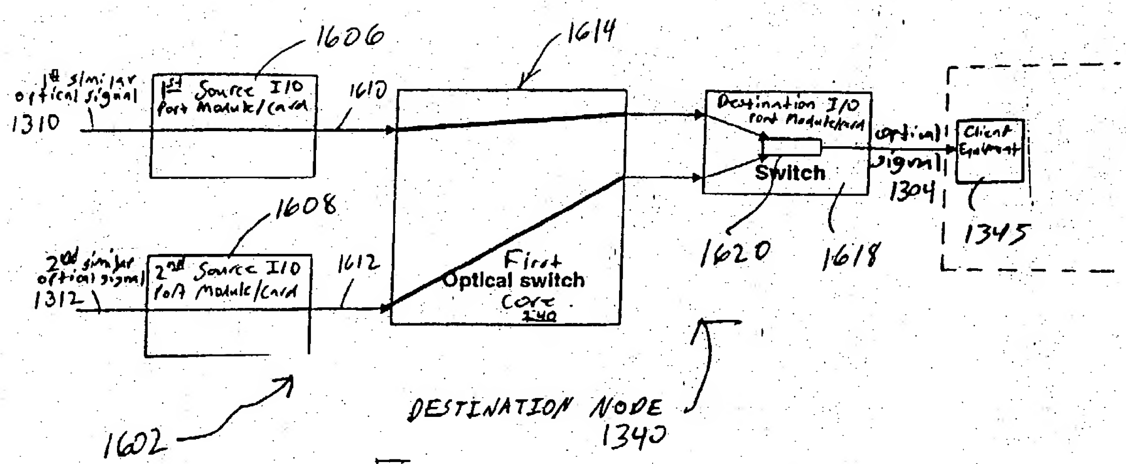


FIG. 16A

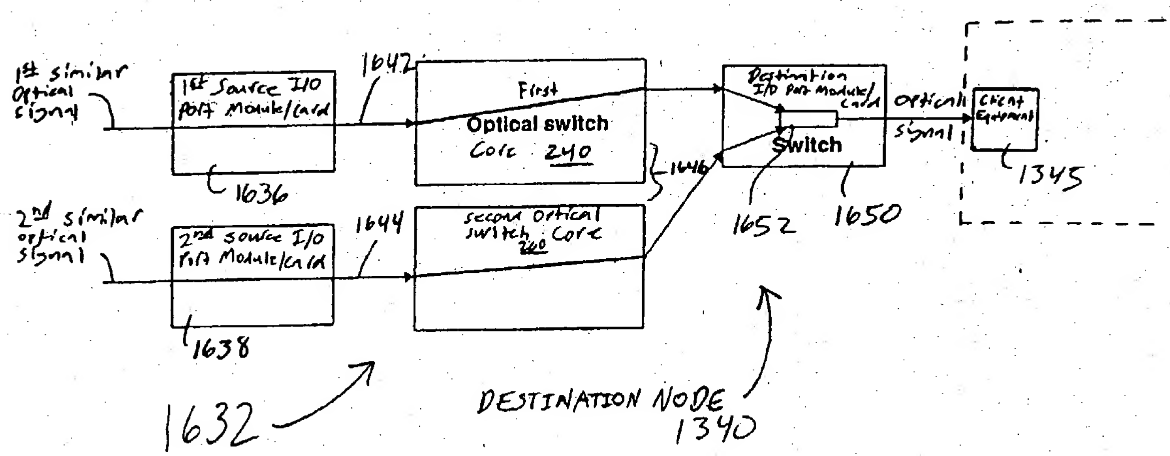


FIG. 16B

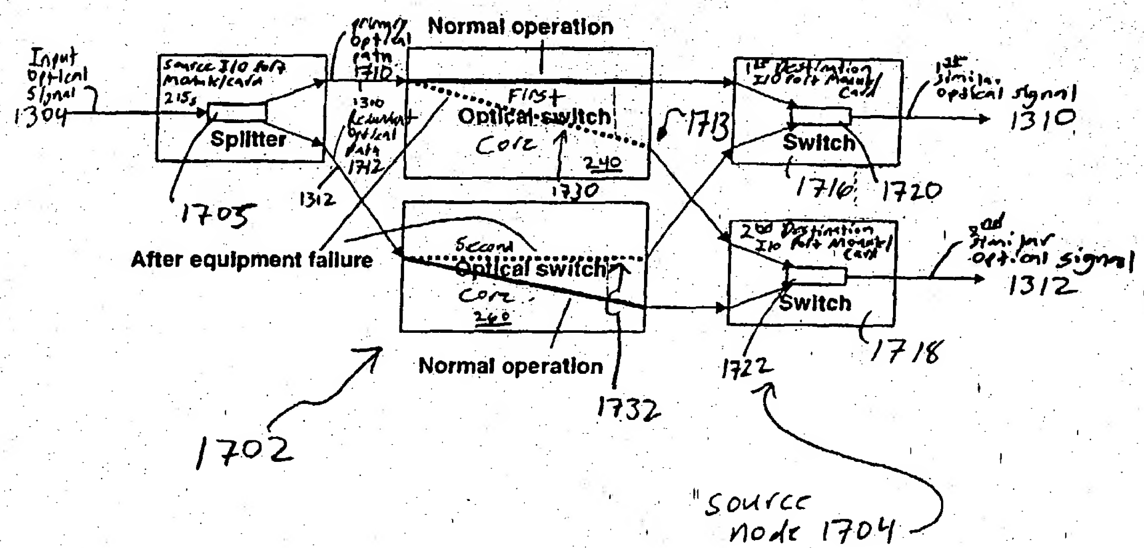

Input optical signal 1304
Source I/O Port Module/card 215s
Splitter
1705
primary optical path 1710
1310
Redundant optical path 1712
1312
Normal operation
First Optical switch Core 240
1730
1713
After equipment failure
Second Optical switch Core 260
Normal operation
1732
1702
1st Destination I/O Port Module Card
Switch
1716
1720
1st similar optical signal 1310
2nd Destination I/O Port Module Card
Switch
1718
1722
2nd similar optical signal 1312
"source node 1704

FIG. 17